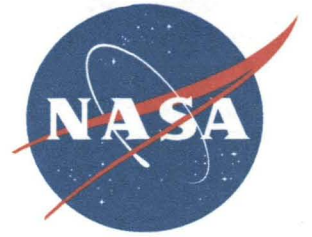


National Aeronautics and Space Administration



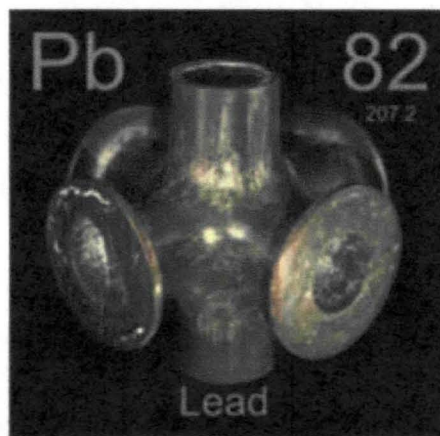
# NASA-DoD Lead-Free Electronics Project

Pb-free Electronics Risk Management  
(PERM) Consortium

September 27, 2011

# Why Lead-Free Electronics?

- Restriction and elimination of lead (Pb) in electronics products enacted by the European Union
  - ❑ Restriction of Hazardous Substances (RoHS) in Electrical and Electronic Equipment; Waste from Electrical and Electronic Equipment (WEEE)] and Pacific-Rim geographical regions (circa 2006).
- Non-U.S. countries continue restricting the disposal of electronic products containing Pb.
- The U.S. does not have existing federal legislation, but several states have adopted laws restricting Pb content in the manufacturing and disposal of electronic equipment.
- Aerospace and Defense OEMs are at risk because their collective demand for electronics is low compared to that of commercial manufacturers.



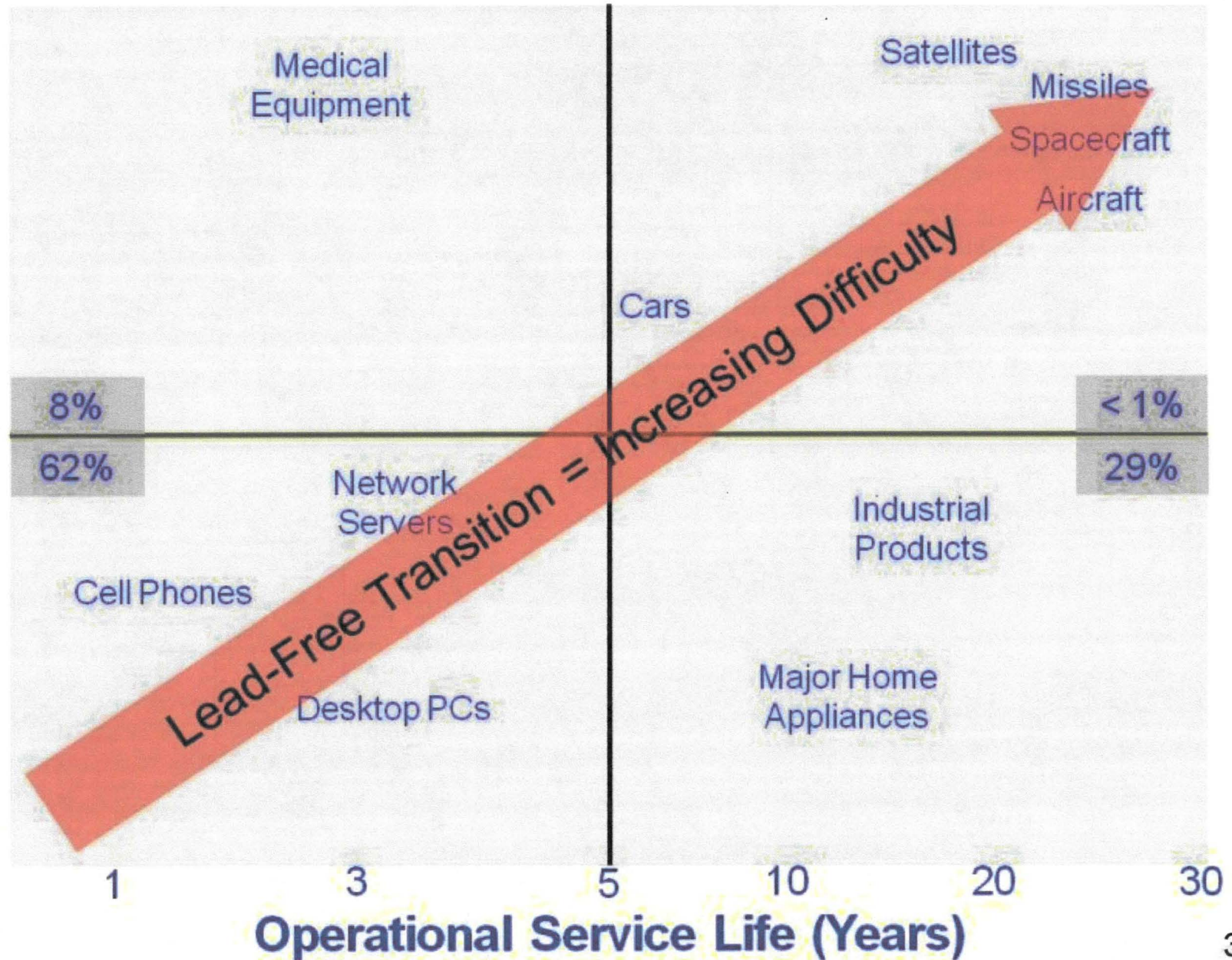


# Military and Aerospace sectors have little influence on the global transition to Lead-Free (<1% Market Share)

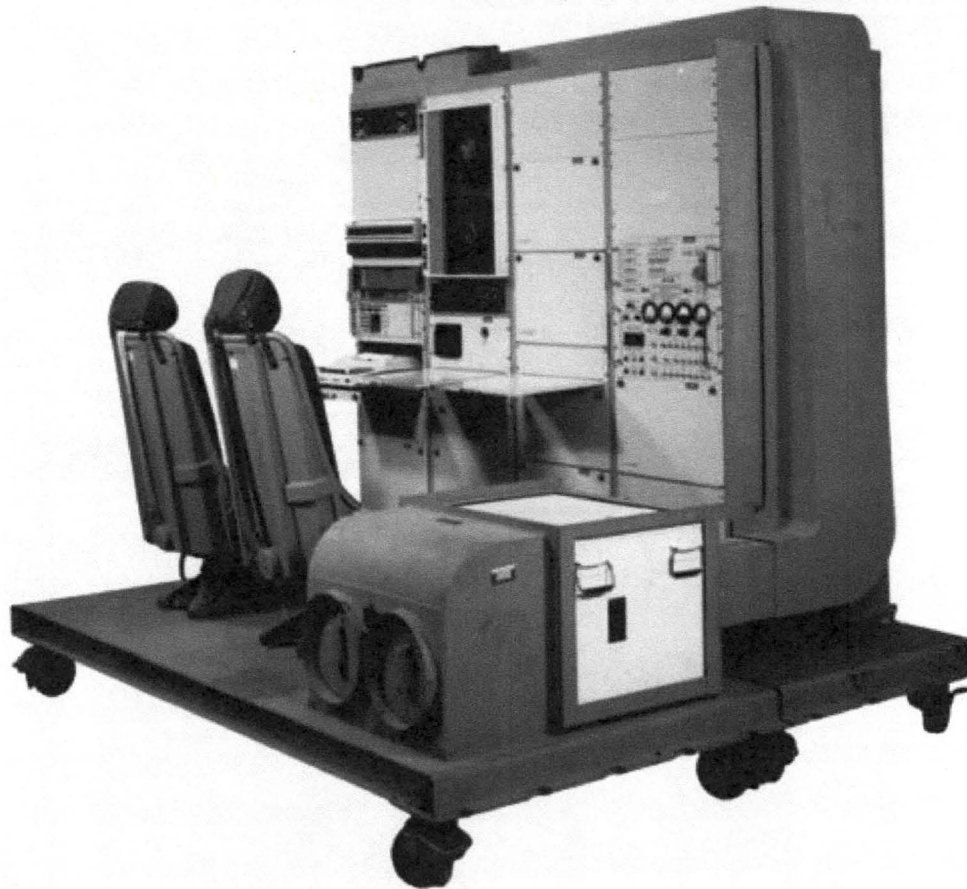
## Harshness of Service Environment

(Temperature, Vibration, Shock, Humidity)

High  
Consequence of Failure  
Low



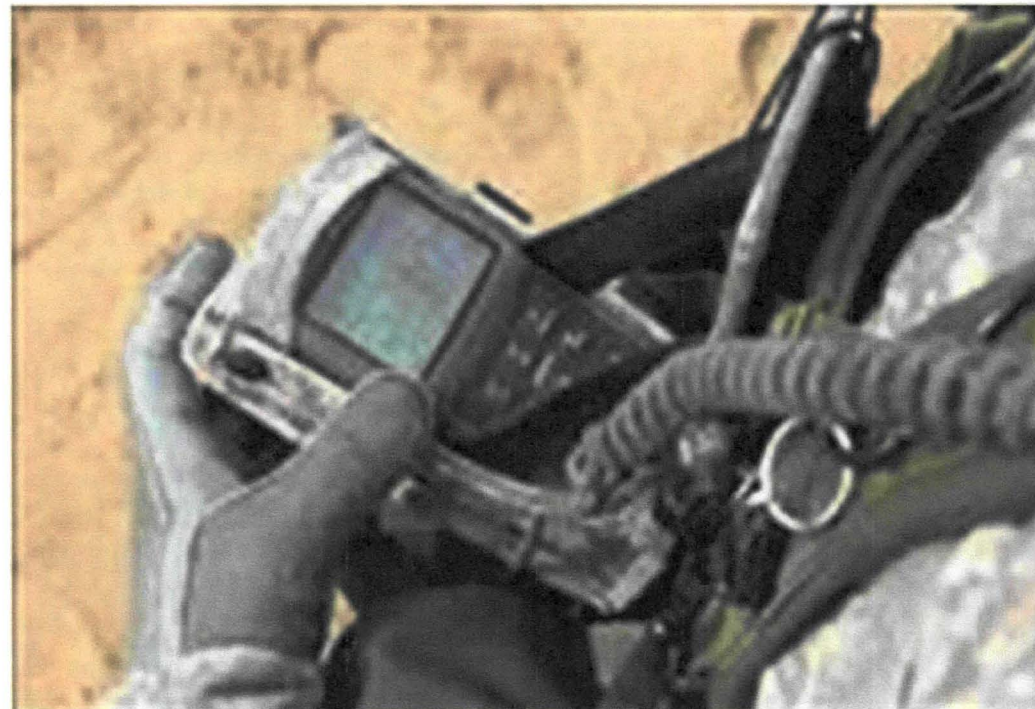
# Processes Must Evolve with Technology Changes



## GPS Technology Evolution

**GPS in 1976 – Hundreds of pounds**

**GPS in 2009 – One pound**



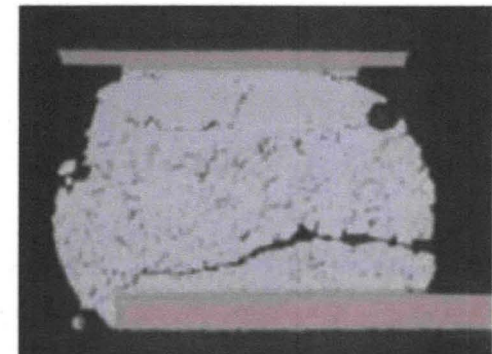
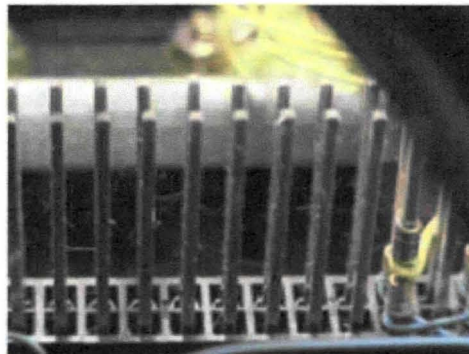
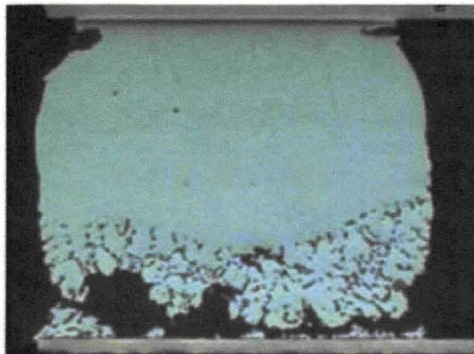
# Need

**Introduction of lead-free components presents one of the greatest risks to the reliability of military and aerospace electronics.**

Customers, suppliers, and maintainers of aerospace and military electronic systems now have a host of concerns such as:

- Electrical shorting due to **tin whiskers**
- Incompatibility of lead-free processes and parameters (including **higher** melting points of lead-free alloys)
- **Unknown** properties that can reduce solder joint reliability

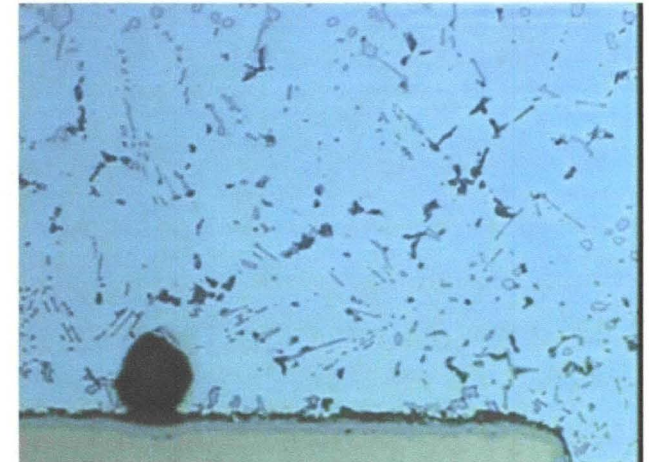
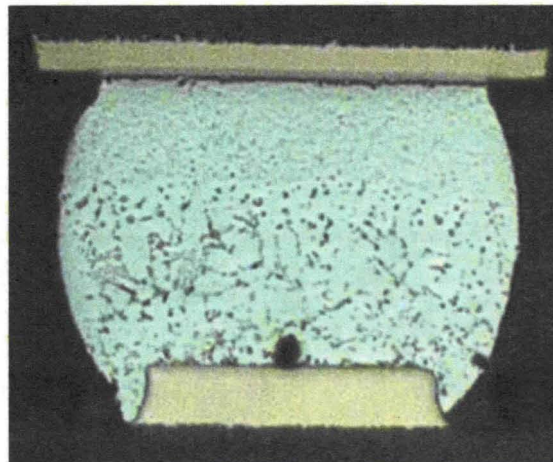
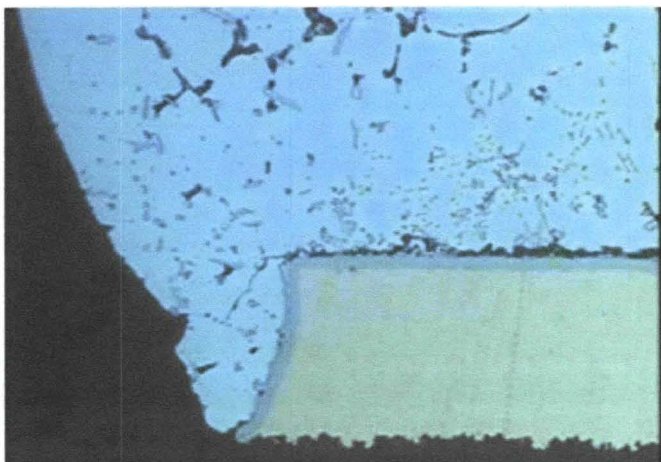
**It will be critical to **fully understand** the implications of reworking lead-free assemblies.**



# Benefit

One of the **largest** most comprehensive projects evaluating the reliability of lead-free solder alloys that:

- Focuses on **rework** of tin-lead and lead-free solder alloys
- Includes **mixing** of tin-lead/lead-free & lead-free/tin-lead solder alloys during **manufacturing** and **rework**.
- Furthers understanding of how lead-free solder interconnects can be **designed** for and **used** in **high reliability** electronic assemblies.



SAC BGA assembled in a conventional SnPb solder process. Failure in temperature cycling (-55 to 125°C) occurred in less than 150 cycles. This type of defect could escape current screening practices.



# Resources

Project documents, test plans, test reports and other associated information will be available on the web:

➤ NASA-DoD Lead-Free Electronics Project:

[http://www.teerm.nasa.gov/projects/NASA\\_DODLeadFreeElectronics\\_Proj2.html](http://www.teerm.nasa.gov/projects/NASA_DODLeadFreeElectronics_Proj2.html)

☐ Joint Test Protocol

☐ Project Plan

☐ Final Test Reports

National Aeronautics and Space Administration

**Technology Evaluation for Environmental  
Risk Mitigation Principal Center**



# Lead-Free Solder Alloys

## SAC305 (Sn3.0Ag0.5Cu)



### ➤ Surface mount assembly

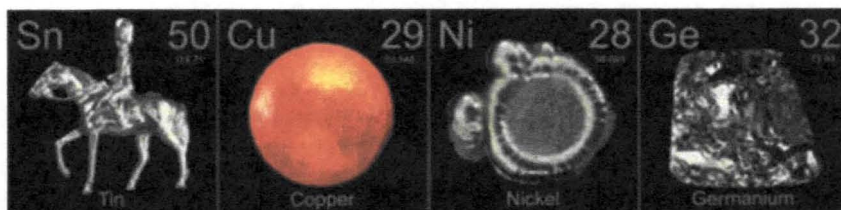
- ☐ Chosen for reflow soldering because it has shown the most promise as a primary replacement for tin-lead solder.
- ☐ Serves best as a “general purpose” alloy. {EnviroMark™ 907 from Kester.}

## SN100C (Sn0.7Cu0.05Ni+Ge)

### ➤ Plated through hole

### ➤ Surface mount assembly

- ☐ This alloy is commercially available.
- ☐ Due to superior performance, industry is switching to nickel stabilized tin-copper alloy over standard tin-copper.
- ☐ Does not require special solder pots.

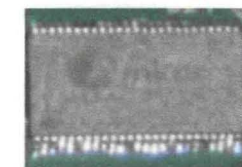
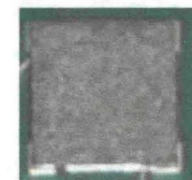
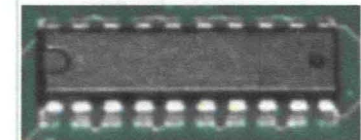
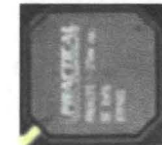
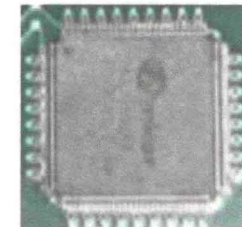
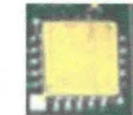
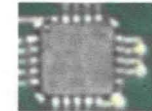


**NS<sup>e</sup>-SOLDER**  
LEAD FREE SOLDERING



# Components

Component Type	Component Finish	Part Number
CLCC-20	SAC305	20LCC-1.27mm-8.90mm-DC-L-Au
	SnPb	Tinning for SAC305 & SnPb
QFN-20	Sn	A-MLF20-5mm-.65mm-DC
	SnPb	
TQFP-144	Sn	A-TQFP144-20mm-.5mm-2.0-DC Tinning for SAC305 & SnPb
	SnPb	
	NiPdAu	
	SAC305	
BGA-225	SnPb	PBGA225-1.5mm-27mm-DC
	SAC405	
PDIP-20	Sn	A-PDIP20T-7.6mm-DC
	NiPdAu	
	SnPb	
CSP-100	SnPb	A-CABGA100-.8mm-10mm-DC Reballed for SN100C
	SAC105	
	SN100C	
TSOP-50	Sn	A-TII-TSOP50-10.16x20.95mm-.8mm-DC
	SnBi	
	SnPb	



Components not to scale

# Test Vehicles

Assembled by BAE Systems - Irving, Texas

➤ 120 = "Manufactured"

➤ 73 = "Rework"

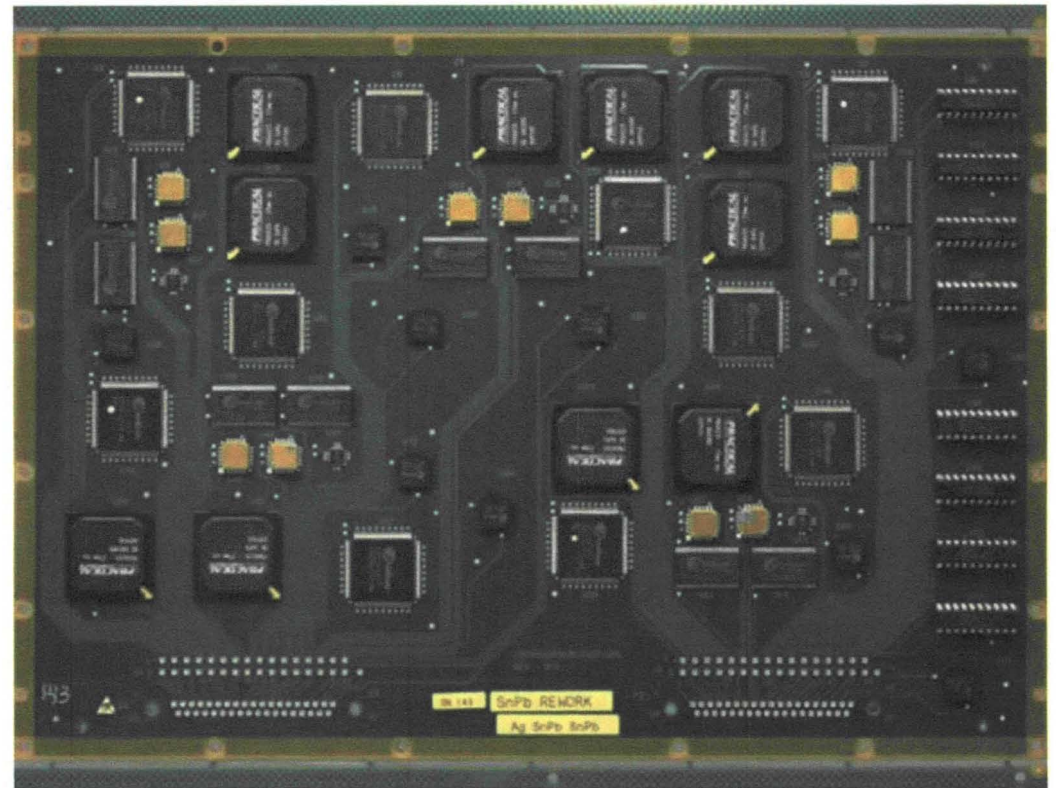
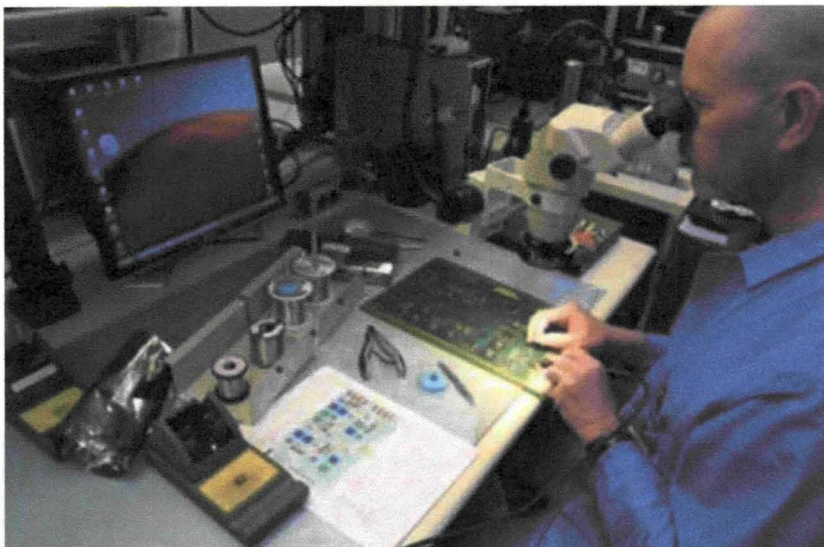
❑ 14.5"X 9"X 0.09"

❑ 6 layers of 0.5 ounce copper

❑ FR4 per IPC-4101/26 with a minimum Tg of 170°C  
(Isola 370HR)

❑ Surface Finish

- Most Immersion Ag
- Some ENIG



# Test Vehicles

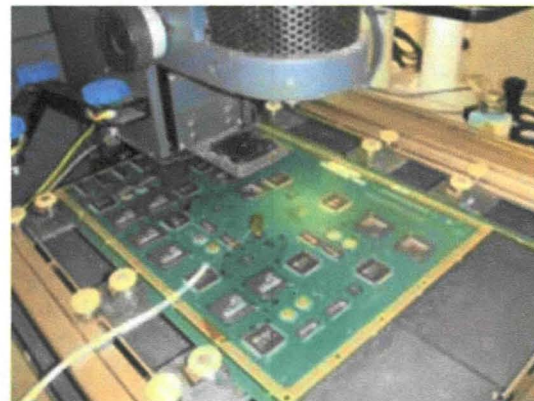
## Assembly Details - SnPb

- Reflow Soldering
- Location – BAE Systems Irving, Texas
- Reflow Profile = SnPb
  - ☐ Preheat = ~ 120 seconds @140-183°C
  - ☐ Solder joint peak temperature = 225°C
  - ☐ Time above reflow = 60-90 sec
  - ☐ Ramp Rate = 2-3 °C/sec
- Wave Soldering
- Location – BAE Systems Irving, Texas
- Wave Profile = SnPb
  - ☐ Solder Pot Temperature = 250°C
  - ☐ Preheat Board T = 101°C
  - ☐ Peak Temperature = 144°C
  - ☐ Speed: 110 cm/min



## Assembly Details – Lead-Free

- Reflow Soldering
- Location – BAE Systems Irving, Texas
- Reflow Profile = SAC305
  - ☐ Preheat = 60-120 seconds @150-190°C
  - ☐ Peak temperature target = 243°C
  - ☐ Reflow: ~20 seconds above 230°C
  - ☐ ~30-90 seconds above 220°C
- Wave Soldering
- Location – Scorpio Solutions
- Wave Profile = SN100C
  - ☐ Solder Pot Temperature = 265°C
  - ☐ Preheat Board T = 134°C
  - ☐ Peak Temperature = 155°C to 175°C
  - ☐ Speed: 90 cm/min





# Test Vehicles

Batch	Test Vehicle Type	Reflow Solder	Wave Solder
A	Lead-Free Rework All Test Vehicles	SAC305	SN100C
B	SnPb Rework* All Test Vehicles	SnPb*	SnPb*
C	SnPb Manufactured Test Vehicles Thermal Cycle and Combined Environments	SnPb	SnPb
D	SnPb Manufactured Test Vehicles Vibration, Mechanical Shock and Drop	SnPb	SnPb
E	Lead-Free Manufactured Test Vehicles Thermal Cycle and Combined Environments	SAC305	SN100C
F	Lead-Free Manufactured Test Vehicles Vibration, Mechanical Shock and Drop	SAC305	SN100C
G	Lead-Free Manufactured Test Vehicles Thermal Cycle and Combined Environments	SN100C	SN100C
H	Lead-Free Manufactured Test Vehicles Vibration, Mechanical Shock and Drop	SN100C	SN100C
I	Lead-Free Manufactured Test Vehicles Crane Rework Effort	SN100C	SN100C

\* NOTE: Lead-Free profiles will be used for reflow and wave soldering

**Component finishes vary {SnPb & lead-free} across all test vehicle types, creating a multitude of solder alloy combinations**

For this project:

- Forward Compatibility is a SnPb component attached to a printed wiring assembly using Pb-free solder with a Pb-free profile.
- Backward compatibility is a Pb-free component attached to a printed wiring assembly using SnPb solder with a SnPb solder profile.



# Test Vehicles

Solder alloy combinations generated during initial assembly

		Component Finish										
		SAC405	SAC305	SAC305 Dip	SAC105	SN100C	NiPdAu	SnBi	Sn	Matte Sn	SnPb	SnPb Dip
Solder Alloy	SAC305	BGA	CLCC	TQFP	CSP		TQFP	TSOP	TSOP	QFN TQFP	BGA CLCC CSP QFN TSOP	TQFP
	SN100C	BGA	CLCC		CSP	CSP	PDIP	TSOP	PDIP TSOP	QFN TQFP	BGA CLCC CSP TSOP	TQFP
	SnPb	BGA	CLCC		CSP		PDIP TQFP	TSOP	PDIP TSOP	QFN TQFP	BGA CLCC CSP PDIP QFN TSOP	TQFP

# "Rework" Test Vehicles



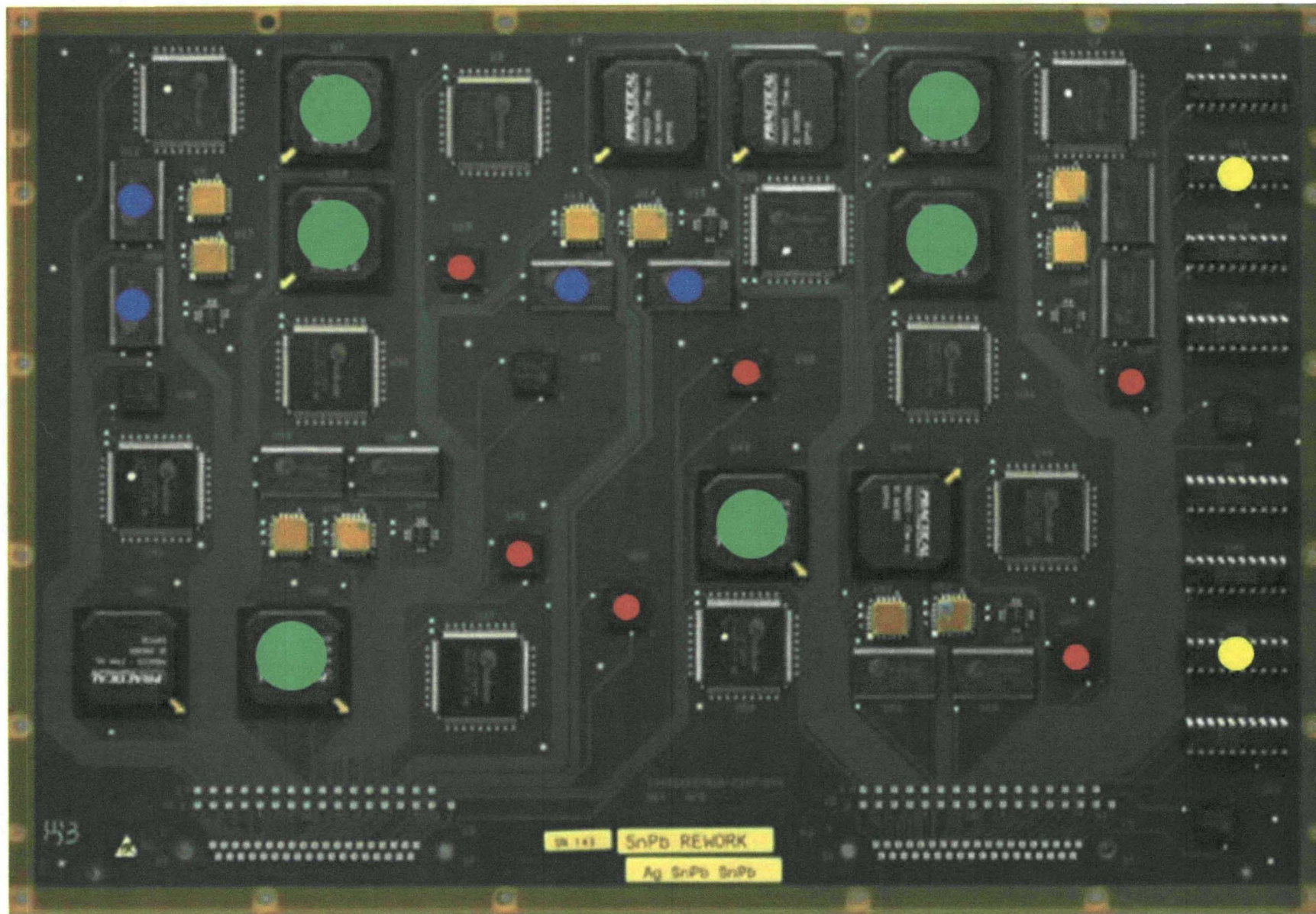
## Reworked Components

U18 – BGA-225  
U43 – BGA-225  
U06 – BGA-225  
U02 – BGA-225  
U21 – BGA-225  
U56 – BGA-225

U33 – CSP-100  
U50 – CSP-100  
U19 – CSP-100  
U37 – CSP-100  
U42 – CSP-100  
U60 – CSP-100

U11 – PDIP-20  
U51 – PDIP-20

U12 – TSOP-50  
U25 – TSOP-50  
U24 – TSOP-50  
U26 – TSOP-50



# Component Finish/Solder Combinations

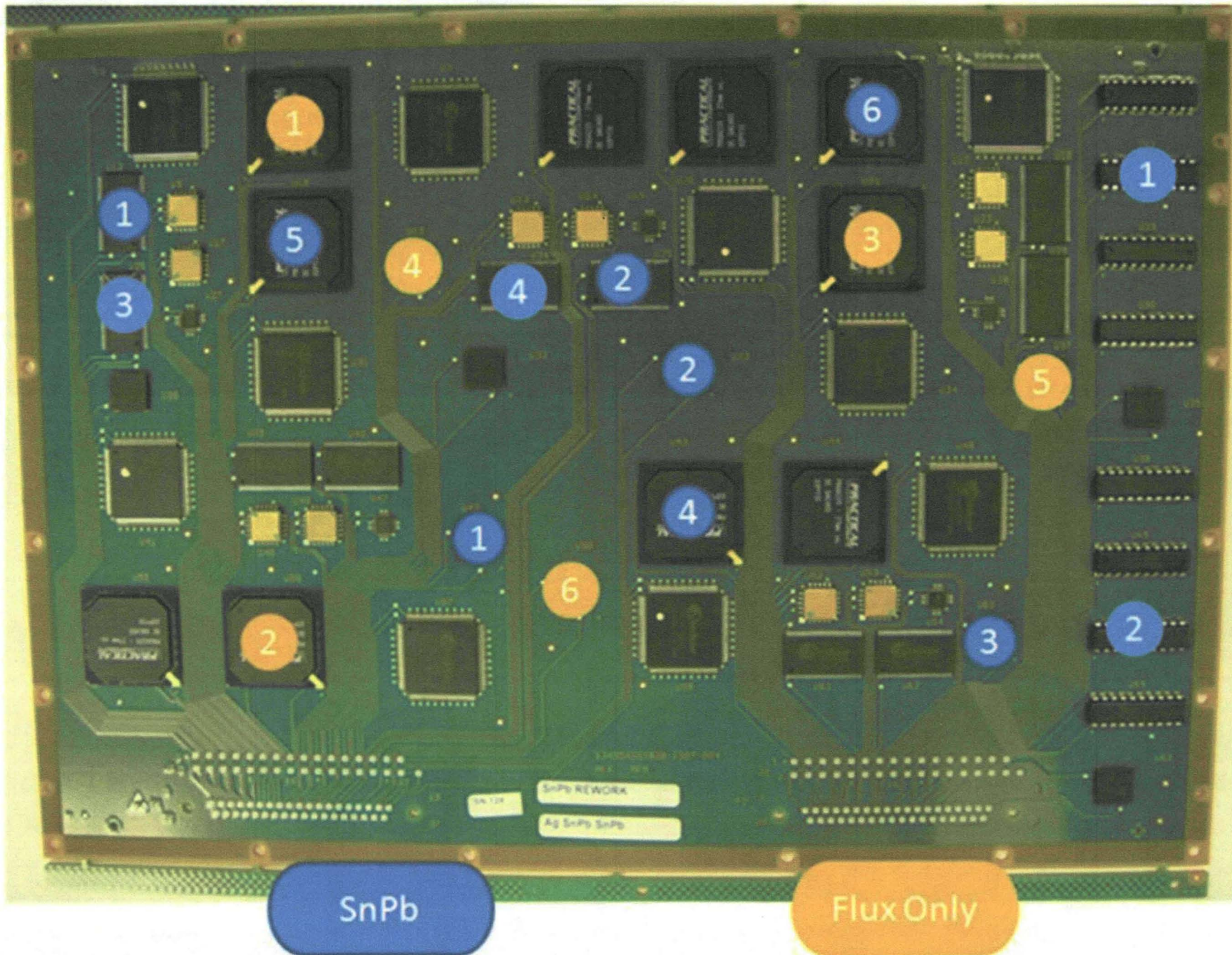
## SnPb Rework



**Lead-Free components introduced into a SnPb assembly**

RefDes	Component	Original Component Finish	Reflow Solder	Wave Solder	New Component Finish	Rework Solder
U18	BGA-225	SnPb	SnPb		SAC405	SnPb
U43	BGA-225	SnPb	SnPb		SAC405	SnPb
U06	BGA-225	SnPb	SnPb		SAC405	SnPb
U02	BGA-225	SnPb	SnPb		SnPb	Flux Only
U21	BGA-225	SnPb	SnPb		SnPb	Flux Only
U56	BGA-225	SnPb	SnPb		SnPb	Flux Only
U33	CSP-100	SnPb	SnPb		SAC105	SnPb
U50	CSP-100	SnPb	SnPb		SnPb	Flux Only
U19	CSP-100	SnPb	SnPb		SnPb	Flux Only
U37	CSP-100	SnPb	SnPb		SnPb	Flux Only
U42	CSP-100	SnPb	SnPb		SAC105	SnPb
U60	CSP-100	SnPb	SnPb		SAC105	SnPb
U11	PDIP-20	SnPb		SnPb	Sn	SnPb
U51	PDIP-20	SnPb		SnPb	Sn	SnPb
U12	TSOP-50	SnPb	SnPb		SnPb	SnPb
U25	TSOP-50	SnPb	SnPb		SnPb	SnPb
U24	TSOP-50	SnPb	SnPb		Sn	SnPb
U26	TSOP-50	SnPb	SnPb		Sn	SnPb

# Rework Procedure – SnPb Rework



# Component Finish/Solder Combinations

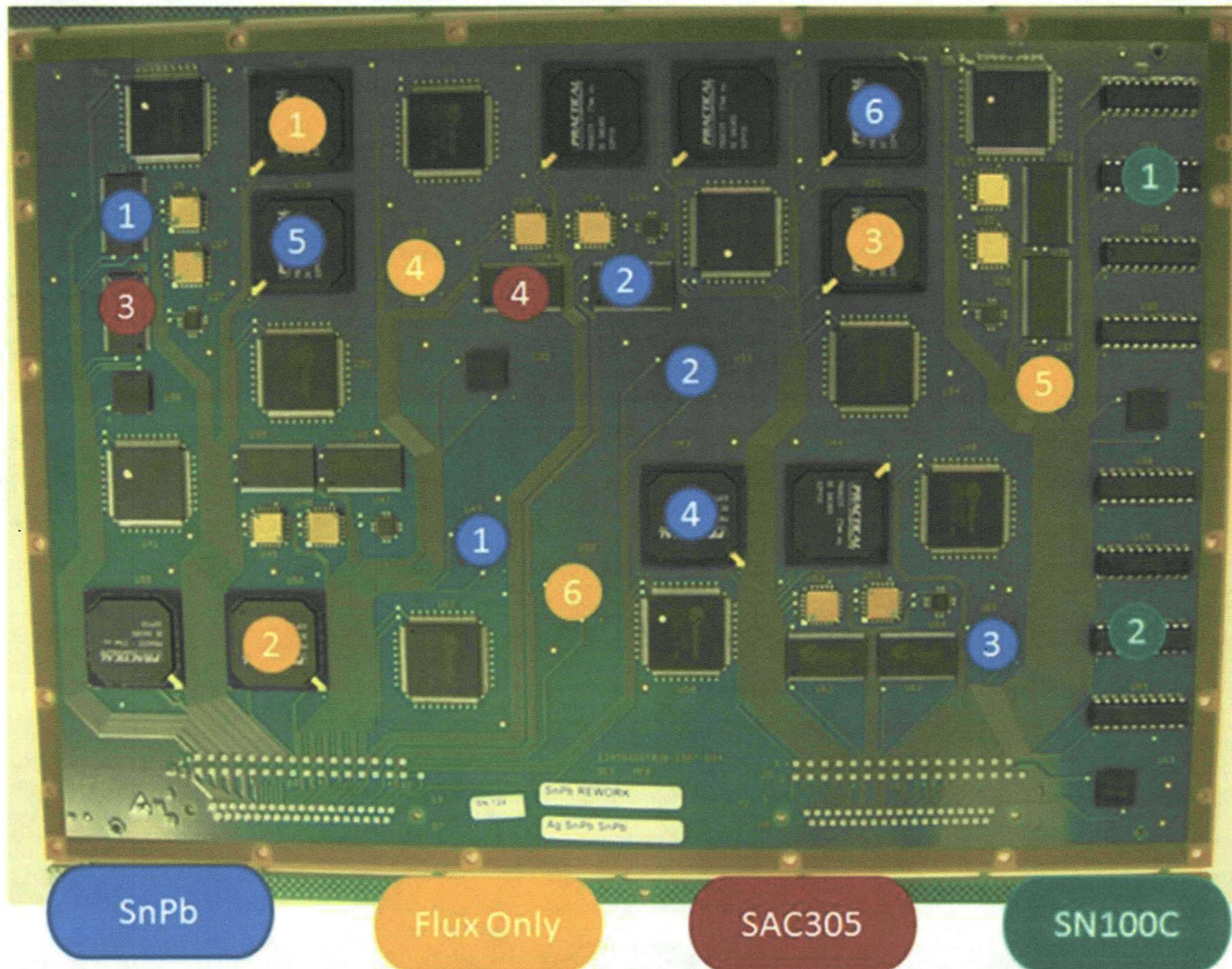
## Lead-Free Rework



**SnPb solder introduced into a lead-free assembly**

RefDes	Component	Original Component Finish	Reflow Solder	Wave Solder	New Component Finish	Rework Solder
U18	BGA-225	SAC405	SAC305		SAC405	SnPb
U43	BGA-225	SAC405	SAC305		SAC405	SnPb
U06	BGA-225	SAC405	SAC305		SAC405	SnPb
U02	BGA-225	SAC405	SAC305		SAC405	Flux Only
U21	BGA-225	SAC405	SAC305		SAC405	Flux Only
U56	BGA-225	SAC405	SAC305		SAC405	Flux Only
U33	CSP-100	SAC105	SAC305		SAC105	SnPb
U50	CSP-100	SAC105	SAC305		SAC105	Flux Only
U19	CSP-100	SAC105	SAC305		SAC105	Flux Only
U37	CSP-100	SAC105	SAC305		SAC105	Flux Only
U42	CSP-100	SAC105	SAC305		SAC105	SnPb
U60	CSP-100	SAC105	SAC305		SAC105	SnPb
U11	PDIP-20	Sn		SN100C	Sn	SN100C
U51	PDIP-20	Sn		SN100C	Sn	SN100C
U12	TSOP-50	Sn	SAC305		Sn	SnPb
U25	TSOP-50	Sn	SAC305		Sn	SnPb
U24	TSOP-50	SnBi	SAC305		SnBi	SAC305
U26	TSOP-50	SnBi	SAC305		SnBi	SAC305

# Rework Procedure – Lead-Free Rework



# NAVSEA Crane Rework Effort



Built 30 test vehicles (sub-set of the 193 assembled)

- Test vehicles were built with **Lead-Free solder and Lead-Free component finishes only** = similar to Manufactured test vehicles for Mechanical Shock, Vibration and Drop Testing
- Lead-Free alloys, SAC305 and SN100C
- Rework was done using **only SnPb solder**
- Performed multiple pass rework 1 to 2 times on random lead-free DIP, TQFP-144, TSOP-50, LCC and QFN components
- Represents real world scenario for deployed Navy vessels
- Testing


- ☐ Thermal Cycling  
-55°C to +125°C

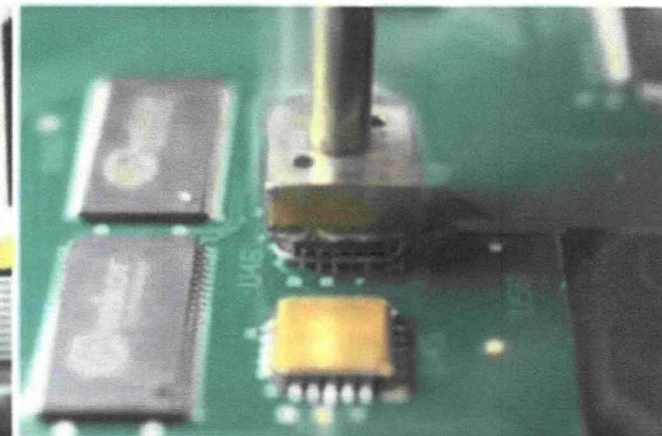
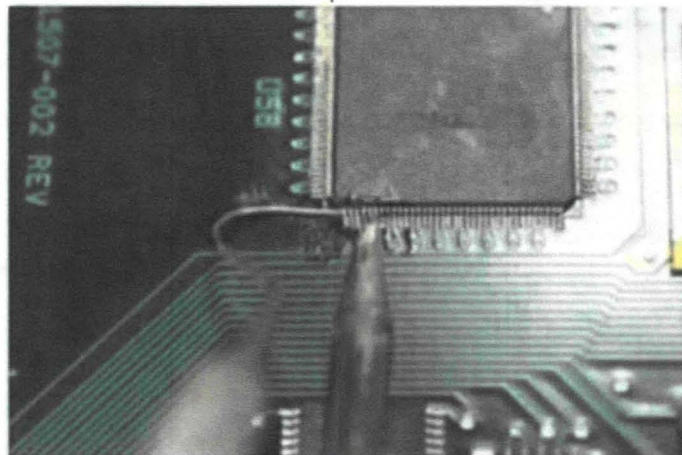
**Rockwell  
Collins**

- ☐ Vibration Testing

 **CELESTICA**






- ☐ Drop Testing

 **CELESTICA**



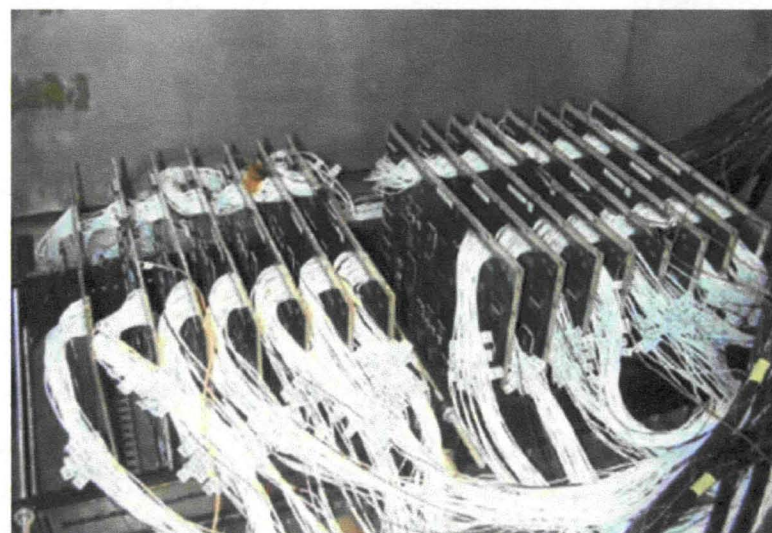


# Testing

- Thermal Cycle Testing (-20/+80°C)  **BOEING®**
- Combined Environments Testing **Raytheon**
- Drop Testing  CELESTICA.
- Thermal Cycle Testing (-55/+125°C) **Rockwell Collins**
- Vibration Testing  **BOEING®**  CELESTICA.
- Mechanical Shock Testing  **BOEING®**

# Thermal Cycling -20° / 80°C

- 5 to 10°C/minute ramp
- 30 minute dwell at 80°C
- 10 minute dwell at -20°C
- Completed about 13,100 cycles





# Thermal Cycling -20° / 80°C








- Approximately 13,100 cycles have been completed.
- Data is following the same trends observed in the JCAA/JGPP LFS Project
- Hopefully the thermal chamber will be allowed to operate until at least 17,000 thermal cycles have been completed.

**JCAA/JGPP LFS Project -**  
Under the conditions of this test, Sn3.9Ag0.6Cu (SAC) and Sn3.4Ag1.0Cu3.3Bi (SACB) were always more reliable than eutectic SnPb regardless of component type (CLCC, TSOP, BGA or TQFP)

Component	Solder/Finish	1st Failure	N10	N63
CLCC-20	SnPb/SnPb	0	0	0
	SAC/SAC	+	++	++
	SACB/SACB	++	++	++
	SAC/SnPb	0	-	0
	SACB/SnPb	+	+	+
TSOP-50	SnPb/SnPb	0	0	0
	SAC/SnCu	+	++	++
	SACB/SnCu	0	+	++
	SAC/SnPb	+	+	+
	SACB/SnPb	--	--	--
BGA-225	SnPb/SnPb	0	0	0
	SAC/SAC	++	++	++
	SACB/SAC	++	++	++
	SAC/SnPb	--	--	--
	SACB/SnPb	--	n/a	--
TQFP-144	SnPb/Sn	0	0	0
	SAC/Sn	++	++	++
	SACB/Sn	++	++	++
TQFP-208	SnPb/NiPdAu	0	0	0
	SAC/NiPdAu	++	++	++
	SACB/NiPdAu	++	++	++

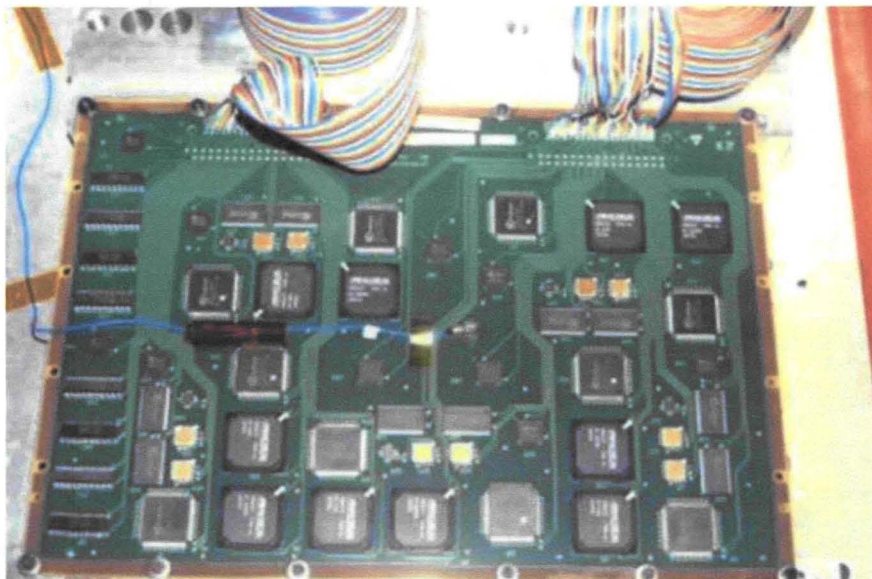


# Testing

- Thermal Cycle Testing (-20/+80°C) 
- Combined Environments Testing 
- Drop Testing  CELESTICA.
- Thermal Cycle Testing (-55/+125°C) 
- Vibration Testing   CELESTICA.
- Mechanical Shock Testing 

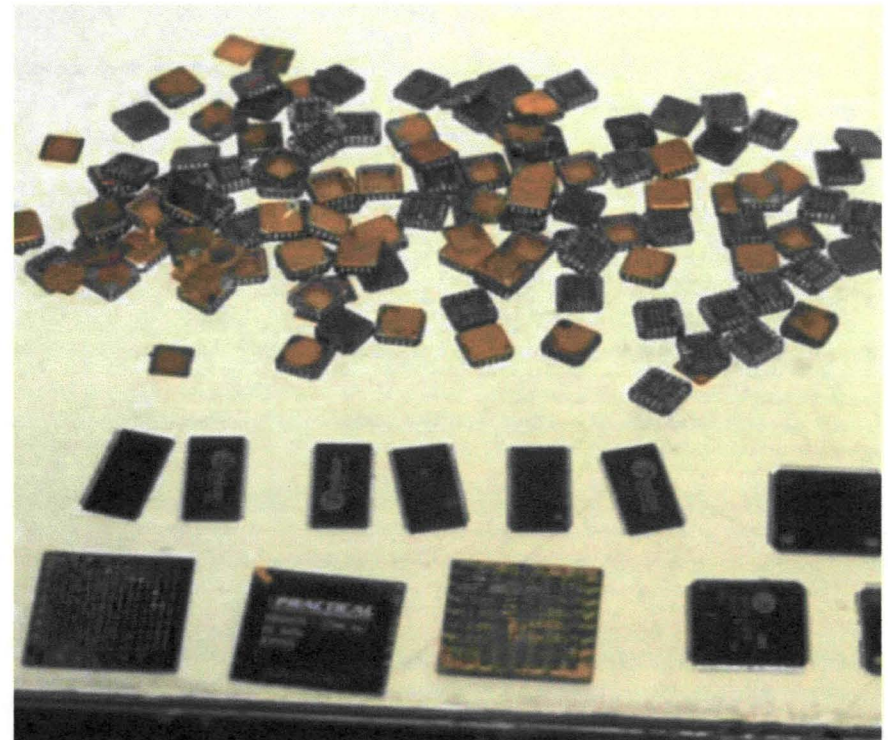
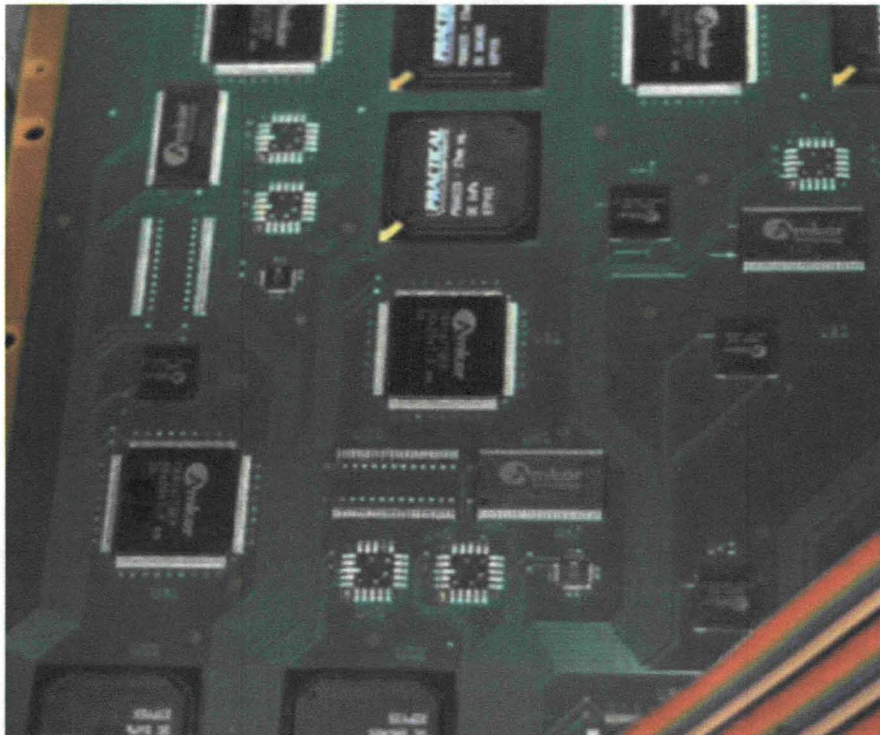
# Combined Environments Test

- -55°C to +125°C
- 20°C/minute ramp
- 15 minute dwell at -55°C and +125°C
- Vibration for the duration of the thermal cycle
- 10  $g_{rms}$  pseudo-random vibration initially
- Increase vibration level 5  $g_{rms}$  after every 50 cycles
- 55  $g_{rms}$  maximum



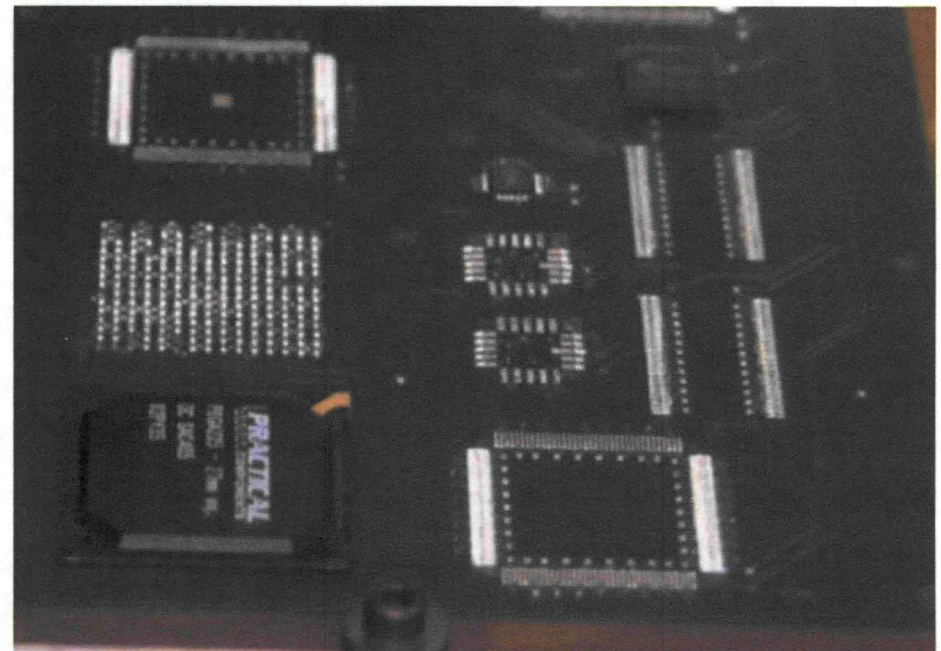
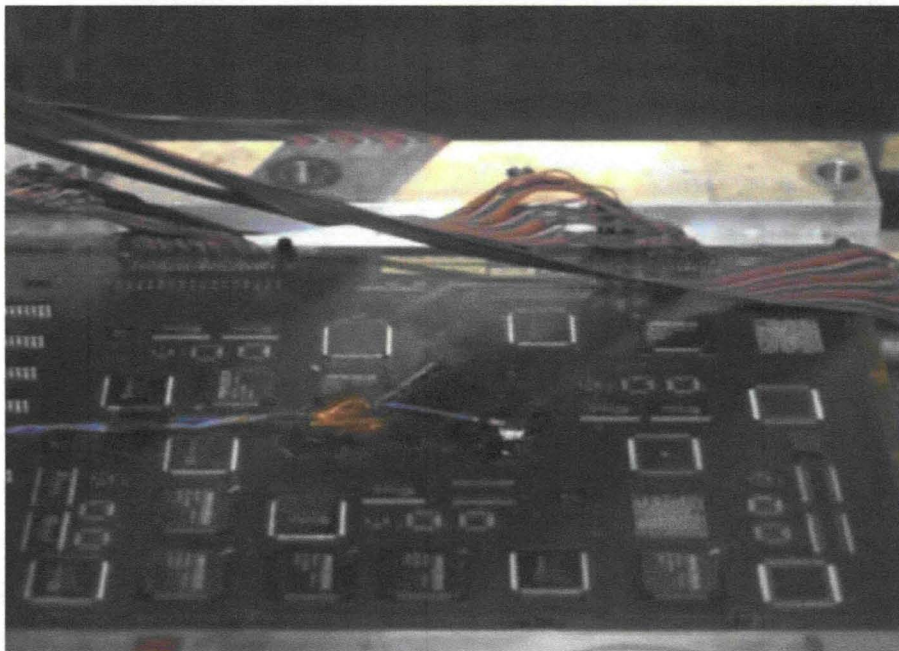
# Combined Environments Test

- Overall, the component type had the greatest effect on solder joint reliability performance.
- Of the surface mount technology, the **BGA-225 components performed the worst.**
- The results of the Combined Environment test results suggest **tin-lead finished components soldered with tin-lead solder paste were the most reliable.**



# Combined Environments Test

- The test results showed the tin-silver-copper soldered components were less reliable than the tin-lead soldered controls.
- The lower reliability of the tin-silver-copper 305 solder joints does not necessarily rule out the use of tin-silver-copper solder alloy on military electronics. **For several of the investigation DOE combinations**, tin-silver-copper 305 solder performed statistically **as good as** or equal to the baseline, **tin-lead solder**.





# Combined Environments Test

## Relative Solder Performance, Manufactured Test Vehicles

- Data which is within 5% of the baseline is denoted with a 0.
- Single symbols, – or +, denote data that is 5% to 20% above (+) or below (-) the baseline.
- Double symbols, -- or ++, denote data that is more than 20% above (++) or below (--) the baseline.
- Green cells denote performance better than the SnPb baseline
- Yellow cells denote performance worse than the SnPb baseline.
- Red cells denote data that is grossly worse than the SnPb baseline.

Board Finish	Component	Alloy	Finish	Nf (1%)	Nf (10%)	Nf (63.2%)
ImAg	BGA-225	SAC305	SAC405	+	0	-
ImAg	BGA-225	SN100C	SAC405	-	-	--
ImAg	BGA-225	SnPb	SAC405	--	--	--
ImAg	BGA-225	SAC305	SnPb	--	--	--
ImAg	BGA-225	SN100C	SnPb	--	--	--
ImAg	BGA-225	SnPb	SnPb	0	0	0
ImAg	CLCC-20	SAC305	SAC305	--	--	-
ImAg	CLCC-20	SN100C	SAC305	--	--	-
ImAg	CLCC-20	SnPb	SAC305	--	--	-
ImAg	CLCC-20	SAC305	SnPb	--	--	--
ImAg	CLCC-20	SN100C	SnPb	--	--	-
ImAg	CLCC-20	SnPb	SnPb	0	0	0
ImAg	CSP-100	SAC305	SAC105	-	0	+
ImAg	CSP-100	SN100C	SAC105	--	--	--
ImAg	CSP-100	SnPb	SAC105	--	--	0
ImAg	CSP-100	SAC305	SnPb	0	0	0
ImAg	CSP-100	SN100C	SnPb	--	-	+
ImAg	CSP-100	SnPb	SnPb	0	0	0
ImAg	TSOP-50	SAC305	SnBi	++	0	--
ImAg	TSOP-50	SN100C	SnBi	--	--	--
ImAg	TSOP-50	SnPb	SnBi	++	+	-
ImAg	TSOP-50	SAC305	SnPb	0	0	0
ImAg	TSOP-50	SN100C	SnPb	--	--	--
ImAg	TSOP-50	SnPb	SnPb	0	0	0

# Combined Environments Test








## Relative Solder Performance, Rework Test Vehicles

- Data which is within 5% of the baseline is denoted with a 0.
- Single symbols, – or +, denote data that is 5% to 20% above (+) or below (–) the baseline.
- Double symbols, -- or ++, denote data that is more than 20% above (++) or below (--) the baseline.
- Green cells denote performance better than the SnPb baseline
- Yellow cells denote performance worse than the SnPb baseline.
- Red cells denote data that is grossly worse than the SnPb baseline.
- Please note, the data for SnPb/SnPb Manufactured test vehicles was used as the baseline for the relative solder performance, rework test vehicles

TV	Board Finish	Component	Alloy	Finish	New Finish	Rework Solder	Nf (1%)	Nf (10%)	Nf (63.2%)
RWK	ImAg	BGA-225	SAC305	SAC405	SAC405	Flux Only	++	++	-
RWK	ImAg	BGA-225	SAC305	SAC405	SAC405	SnPb	++	++	-
RWK	ImAg	BGA-225	SAC305	SnPb			++	0	--
RWK	ImAg	BGA-225	SnPb	SAC405			++	++	-
RWK	ImAg	BGA-225	SnPb	SnPb	SAC405	SnPb	--	--	--
RWK	ImAg	BGA-225	SnPb	SnPb	SnPb	Flux Only	++	++	--
MFG	ImAg	BGA-225	SnPb	SnPb			0	0	0
RWK	ImAg	CLCC-20	SAC305	SnPb			--	--	--
RWK	ImAg	CLCC-20	SnPb	SAC305			--	--	--
MFG	ImAg	CLCC-20	SnPb	SnPb			0	0	0
RWK	ImAg	CSP-100	SAC305	SAC 105	SAC 105	Flux Only	--	-	++
RWK	ImAg	CSP-100	SAC305	SAC 105	SAC 105	SnPb	--	--	--
RWK	ImAg	CSP-100	SAC305	SnPb			--	-	0
RWK	ImAg	CSP-100	SnPb	SAC 105			--	--	-
RWK	ImAg	CSP-100	SnPb	SnPb	SAC 105	SnPb			
RWK	ImAg	CSP-100	SnPb	SnPb	SnPb	Flux Only			
MFG	ImAg	CSP-100	SnPb	SnPb			0	0	0
RWK	ImAg	TSOP-50	SAC305	Sn	Sn	SnPb	++	+	-
RWK	ImAg	TSOP-50	SAC305	SnBi	SnBi	SAC305	++	+	--
RWK	ImAg	TSOP-50	SAC305	SnBi			++	++	-
RWK	ImAg	TSOP-50	SAC305	SnPb			++	++	++
RWK	ImAg	TSOP-50	SnPb	Sn			++	++	-
RWK	ImAg	TSOP-50	SnPb	SnBi			++	++	0
RWK	ImAg	TSOP-50	SnPb	SnPb	Sn	SnPb	++	++	-
RWK	ImAg	TSOP-50	SnPb	SnPb	SnPb	SnPb	+	0	-
MFG	ImAg	TSOP-50	SnPb	SnPb			0	0	0



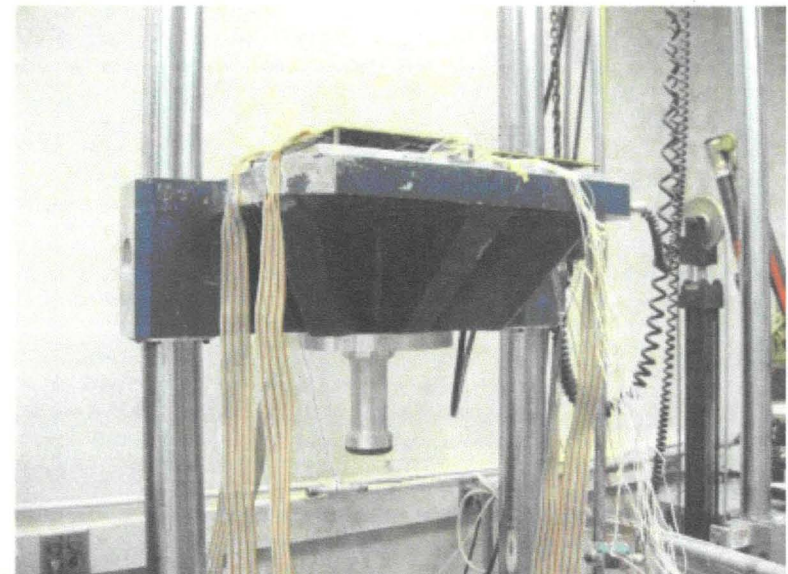
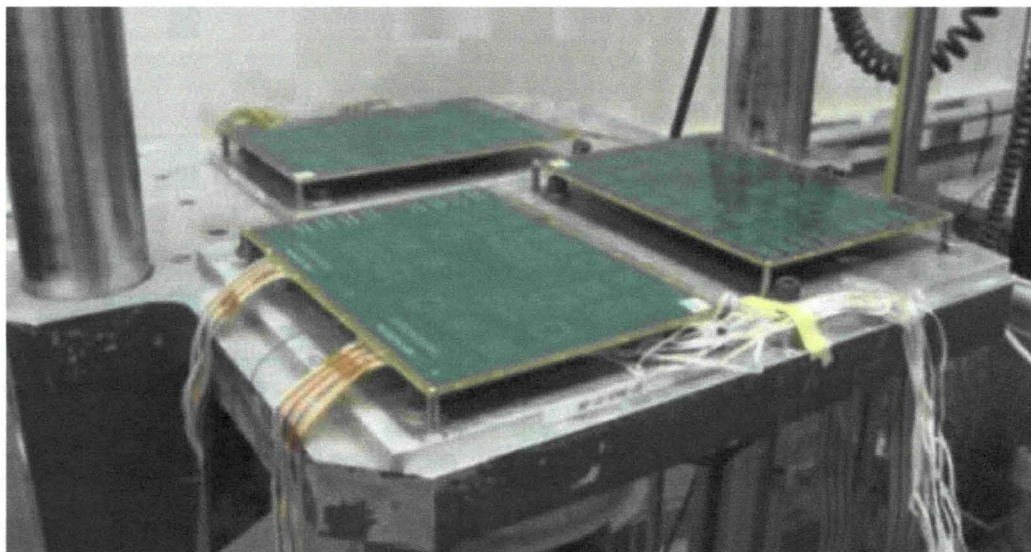
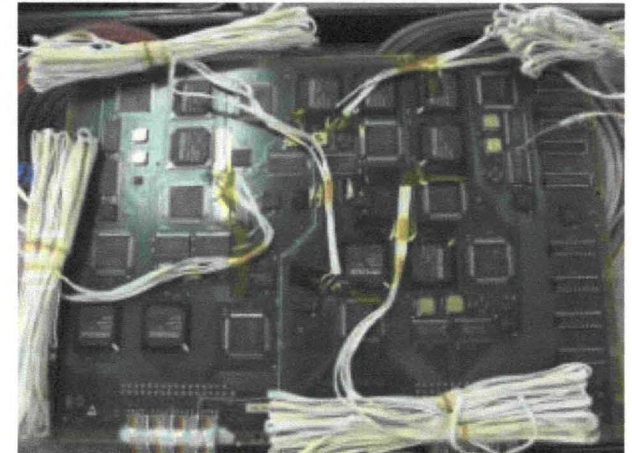
# Testing

- Thermal Cycle Testing (-20/+80°C)  **BOEING®**
- Combined Environments Testing **Raytheon**
- Drop Testing  **CELESTICA**
- Thermal Cycle Testing (-55/+125°C) **Rockwell Collins**
- Vibration Testing  **BOEING®**  **CELESTICA**
- Mechanical Shock Testing  **BOEING®**

# Drop Testing - NSWC Crane Test Vehicles



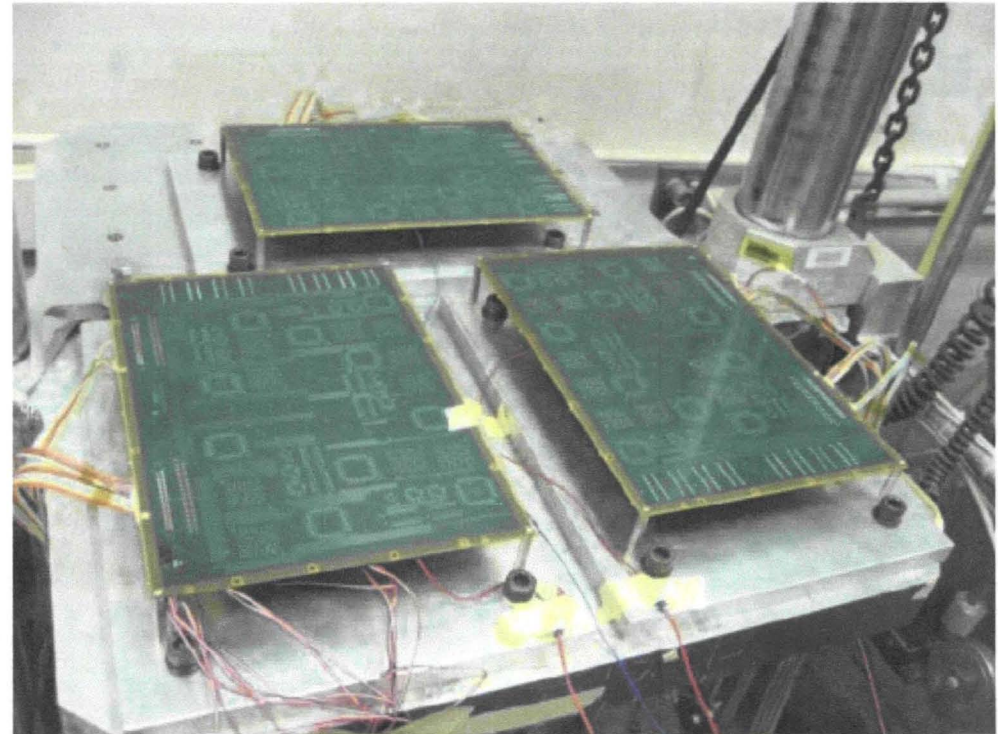
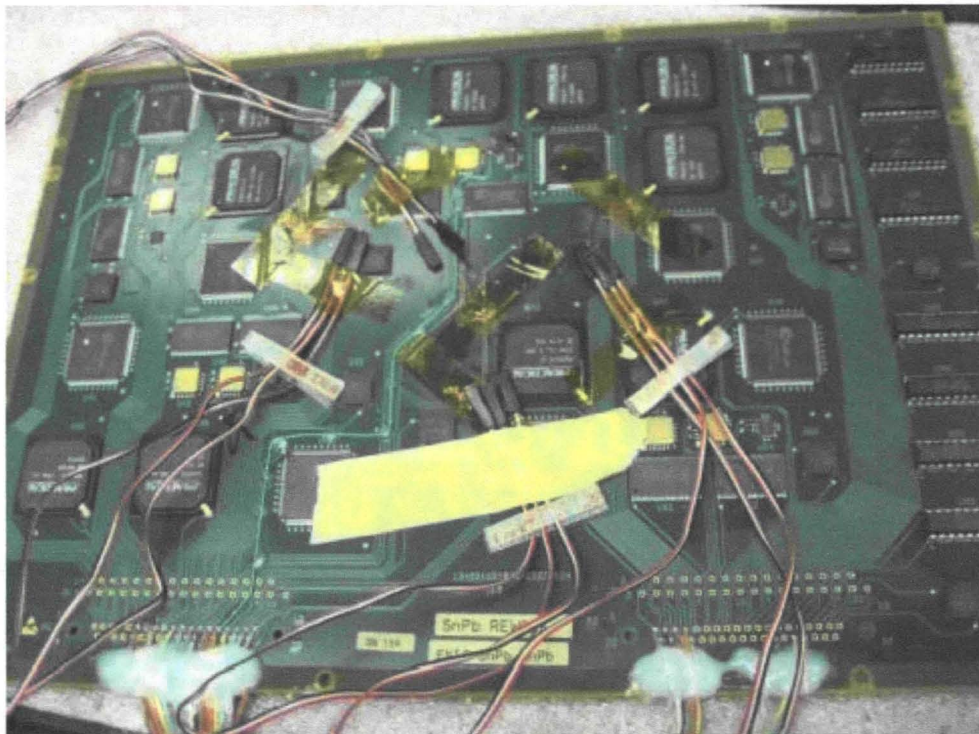
- Shock parameters: 500 G, 2.0 ms duration (340 G for cards 80, 82, 87 for first 10 drops)
- Number of drops: 20
- 9 cards in total / 3 cards tested per drop
- Each card monitored for shock response
- Each card monitored for resistance
- Cards 80, 83, 86 monitored for strain



# Drop Testing - NASA-DoD Test Vehicles

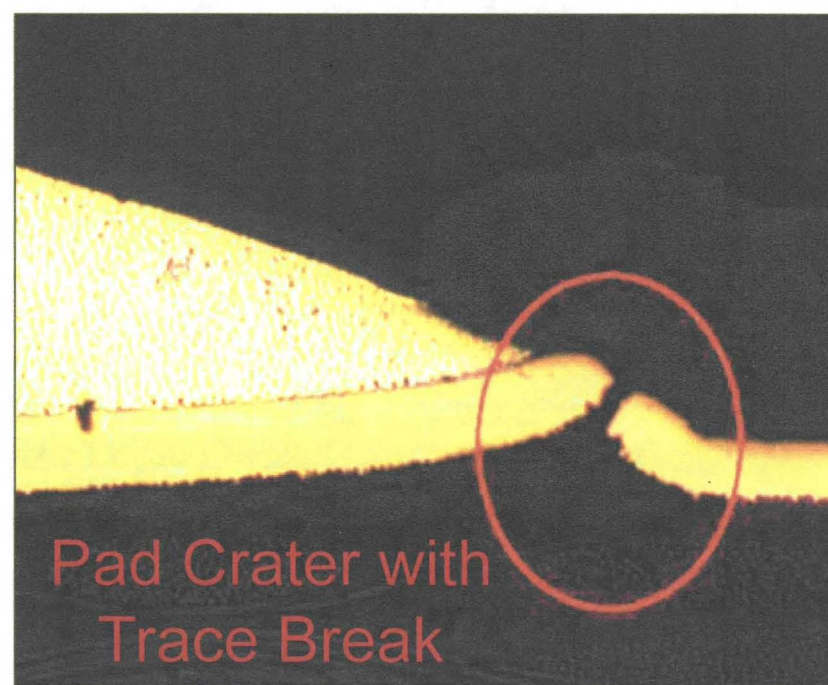
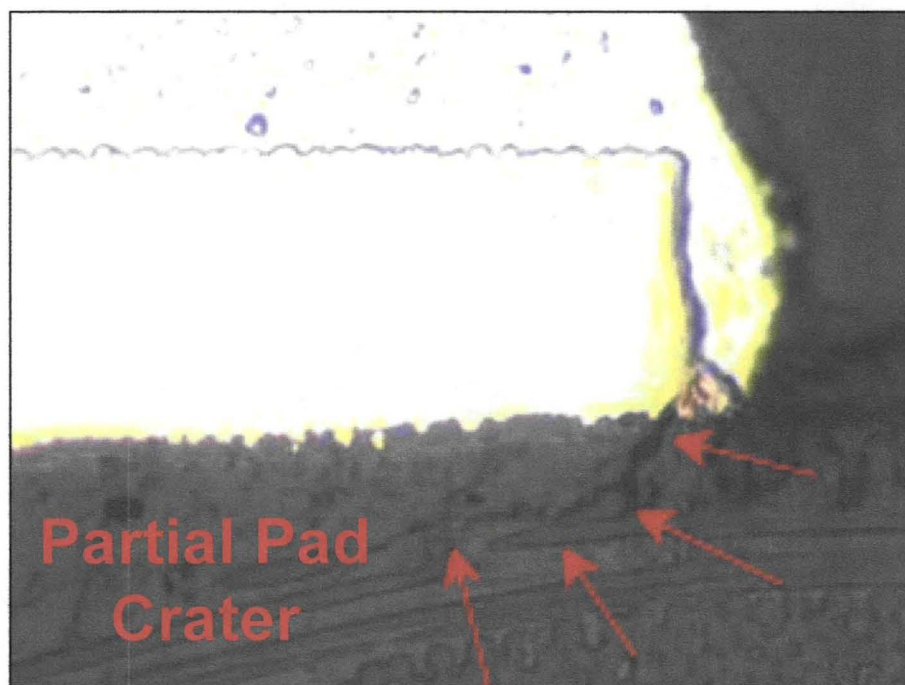


- Shock testing will be conducted in the Z - axis
- 500Gpk input, 2ms pulse duration
- Test vehicles will be dropped until all monitored components fail or 10 drops have been completed

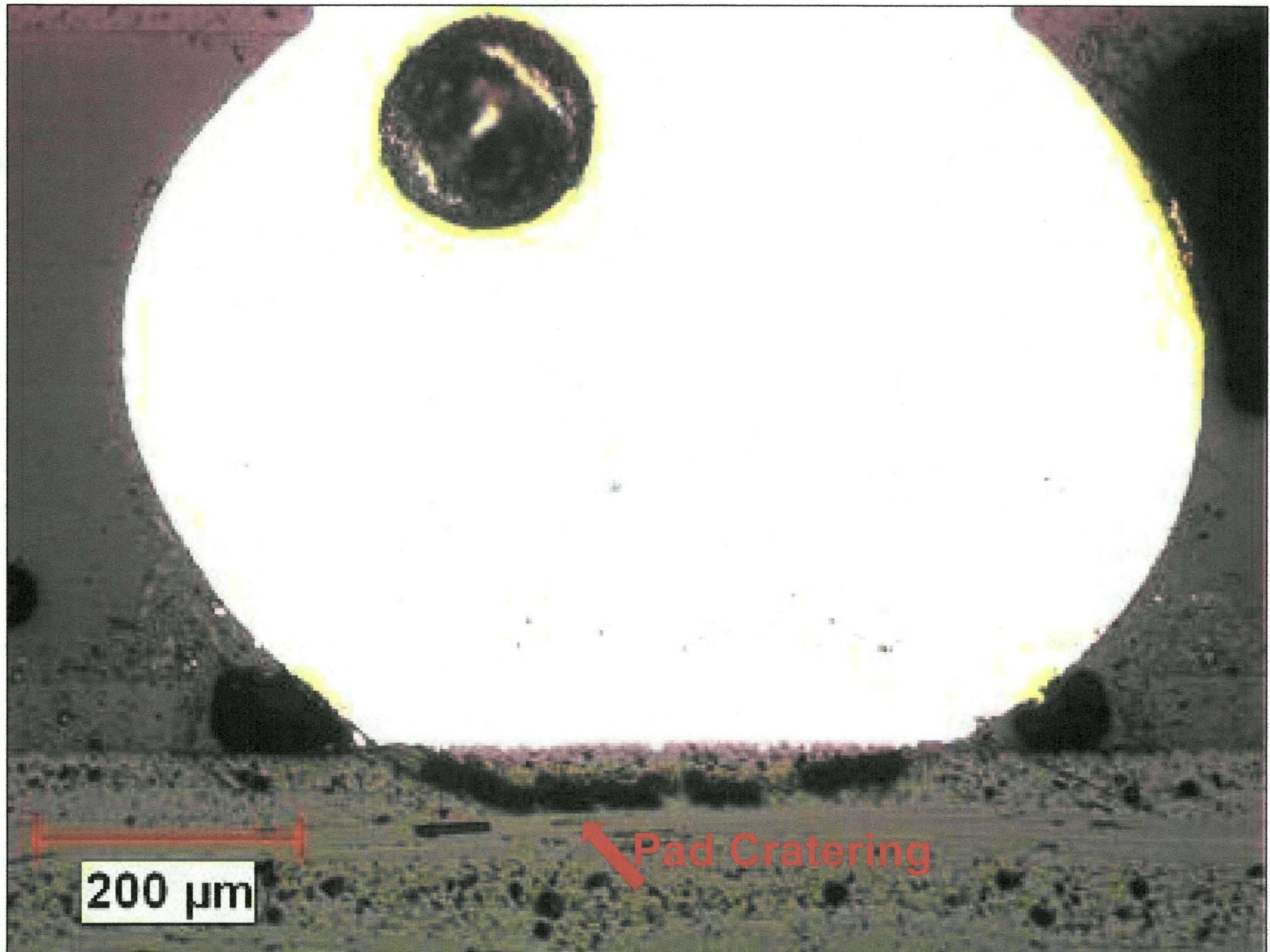


# Drop Testing

- Drop test reliability was **component type dependent**.
- The only component type to show a significant number of electrical failures during this test were the **BGAs**. The BGA-225 electrical failures mostly occurred at or near the corner joints.
- The predominant damage mechanism in drop testing is **pad cratering**. Cracks propagate through the board material between the laminate and glass fiber under the pads.








# Drop Testing





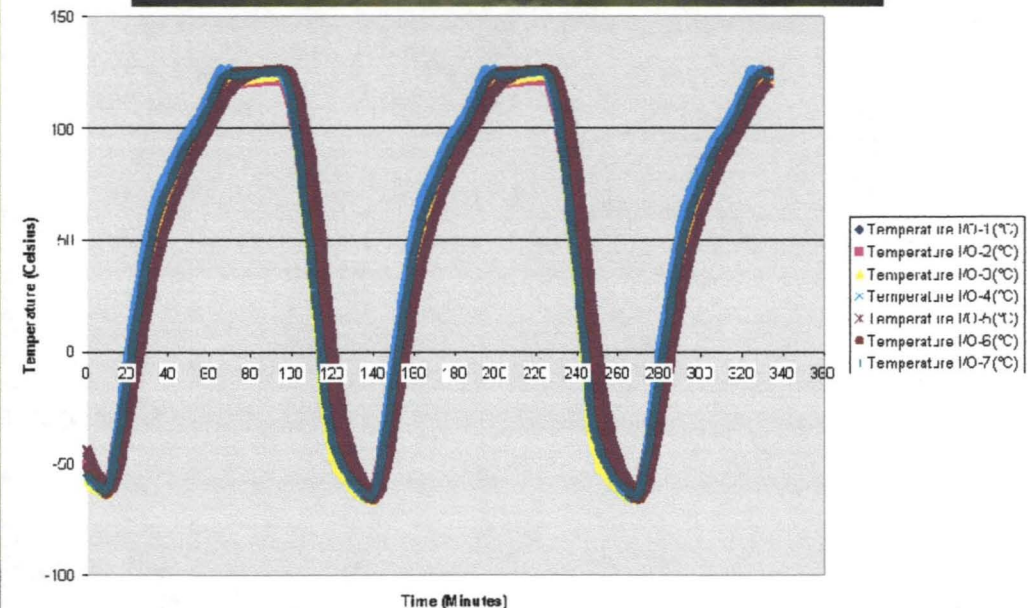
# Testing

- Thermal Cycle Testing (-20/+80°C)  **BOEING®**
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- Thermal Cycle Testing (-55/+125°C) **Rockwell Collins**
- Vibration Testing  **BOEING®**  **CELESTICA**
- Mechanical Shock Testing  **BOEING®**

# Thermal Cycle Testing (-55/+125°C)

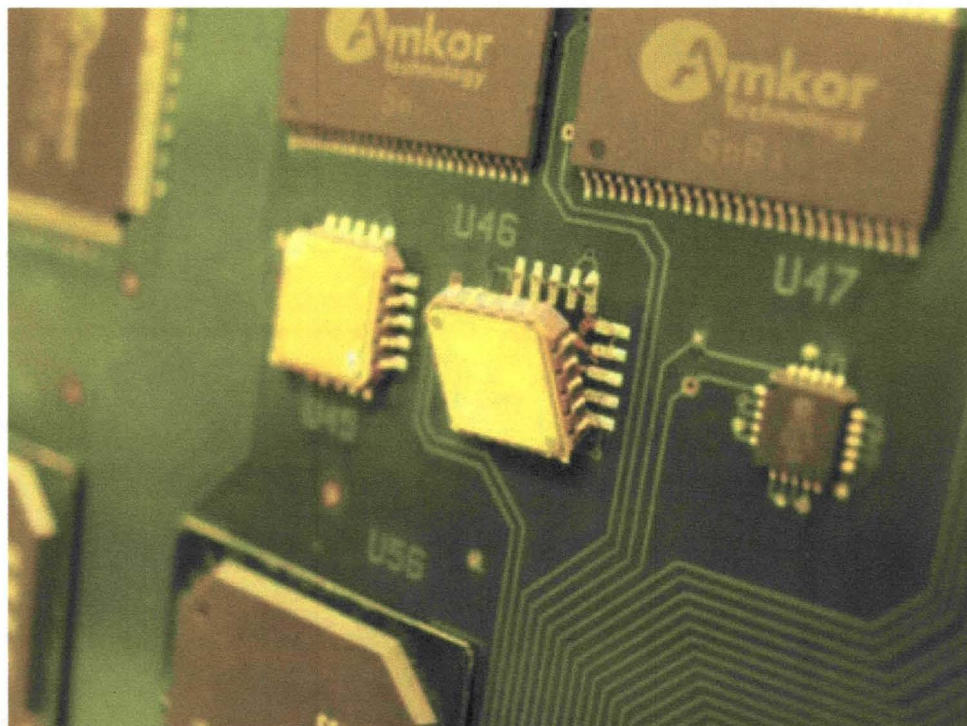


- 5 to 10°C/minute ramp
- 30 minute dwell at 125°C
- 10 minute dwell at -55°C
- Completed 4,068 thermal cycles



# Thermal Cycle Testing (-55/+125°C)

- Completed 4,068 thermal cycles
  - ❑ Initial Analysis = In general, the preliminary results show that the **SnPb** solder alloy **out performed** the two **lead-free** solder alloys in many cases.
  - ❑ However, the performance of the lead-free solder alloys was not without merit. The question to be answered is: “**How good is good enough** for a product application?”



# Thermal Cycle Testing (-55/+125°C)



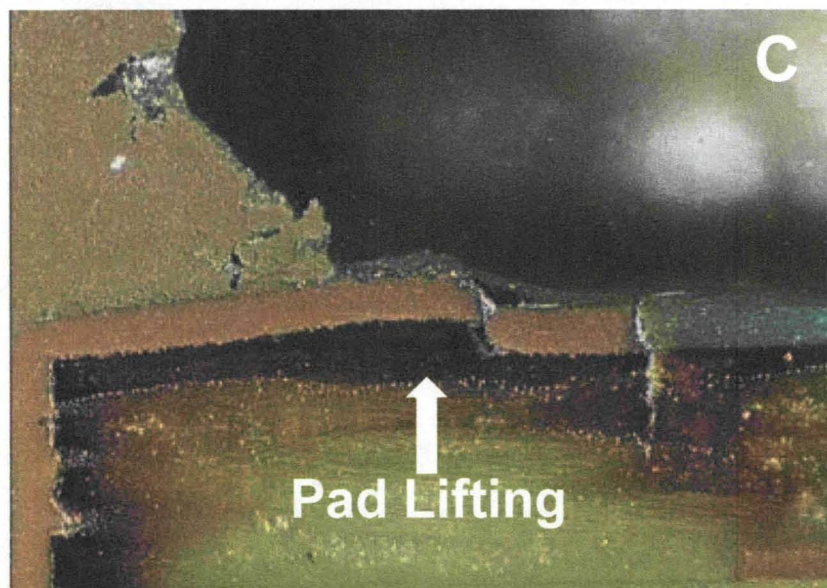
## Manufactured Test Vehicles – Failure Rates

Component Type	Total Failures	Population	Percent Failed
CLCC-20	309	311	99%
QFN-20	88	134	66%
QFP-144	306	309	99%
PBGA-225	253	279	91%
PDIP-20	189	220	86%
CSP-100	252	281	90%
TSOP-50	249	249	100%

## Rework Test Vehicles – Failure Rates






Component Type	Total Failures	Population	Percent Failed
PBGA-225	51	66	77%
PDIP-20	57	60	95%
CSP-100	45	67	67%
TSOP-50	99	99	100%

Three sufficient conditions resulting in unexpectedly high PDIP failures {cracked traces} on *lead-free* assemblies: **A+B+C = Failure**



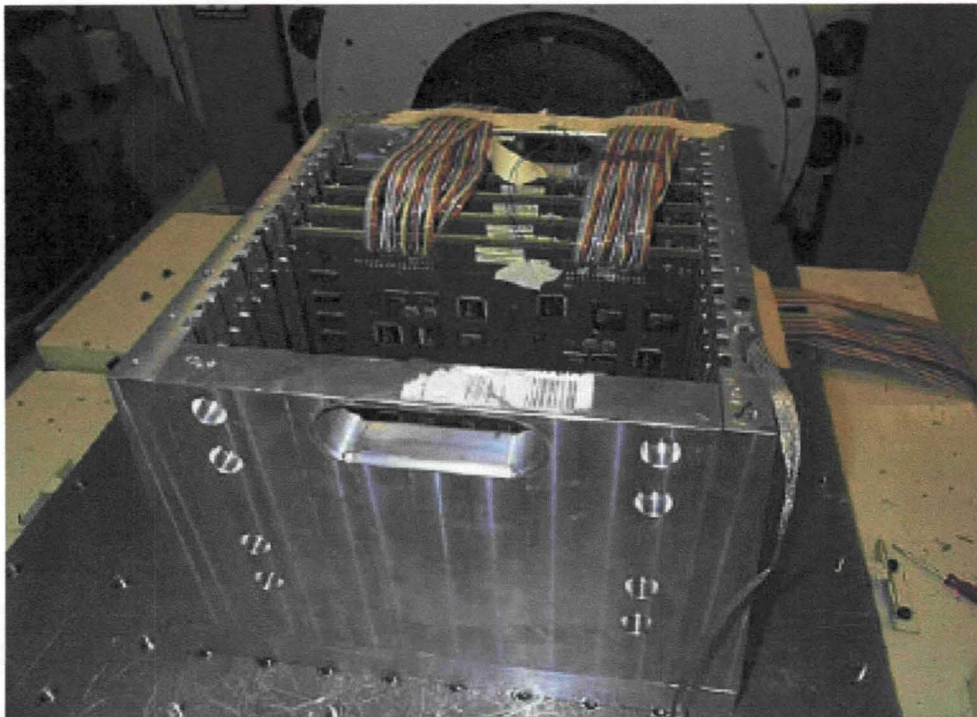


# Testing

- Thermal Cycle Testing (-20/+80°C)  **BOEING**
- Combined Environments Testing **Raytheon**
- Drop Testing  **CELESTICA**
- Thermal Cycle Testing (-55/+125°C) **Rockwell Collins**
- Vibration Testing  **BOEING**  **CELESTICA**
- Mechanical Shock Testing  **BOEING**

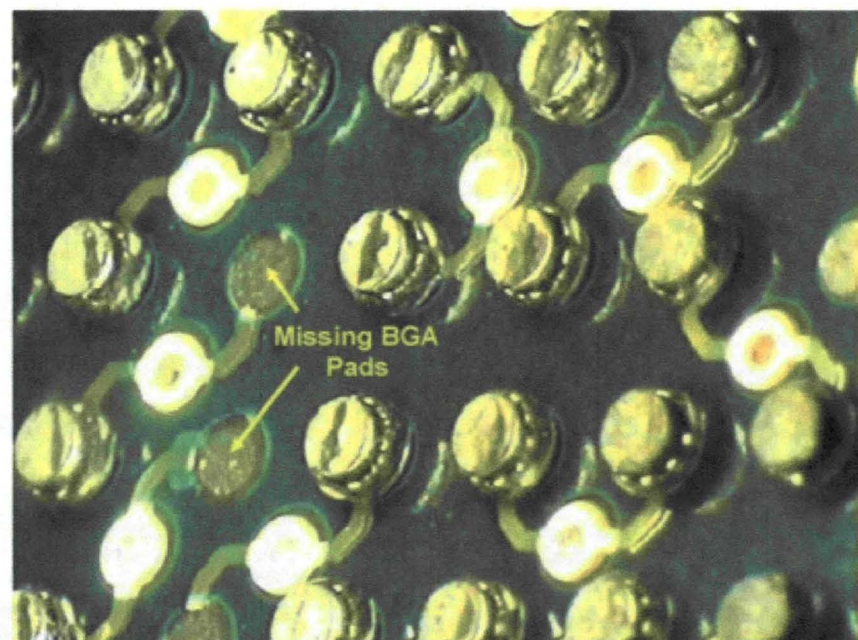
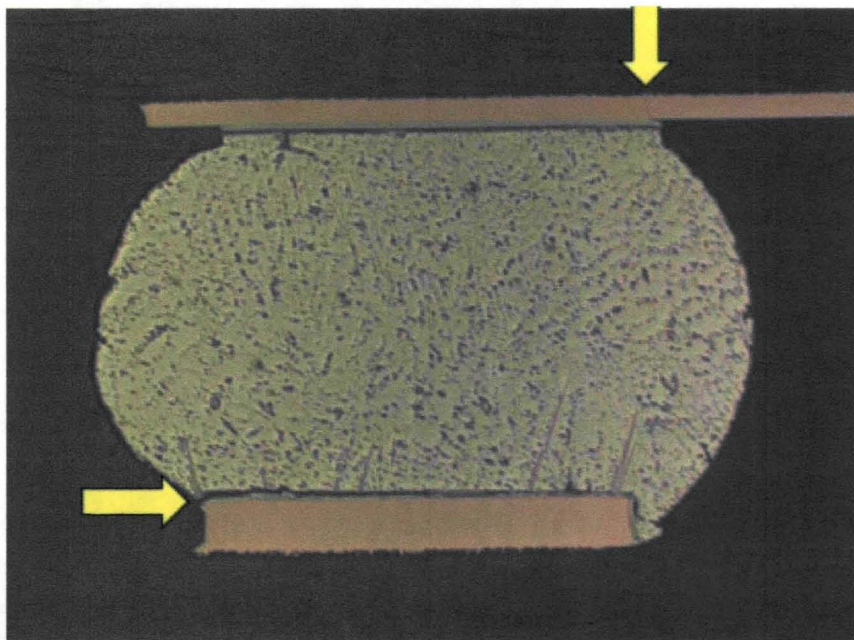
# Vibration Testing

- Subject the test vehicles to  $8.0 \text{ g}_{\text{rms}}$  for one hour.
- Then increase the Z-axis vibration level in  $2.0 \text{ g}_{\text{rms}}$  increments, shaking for one hour per step until the  $20.0 \text{ g}_{\text{rms}}$  level is completed.
- Then subject the test vehicles to a final one hour of vibration at  $28.0 \text{ g}_{\text{rms}}$ .



# Vibration Testing

- The results of this study suggest that for many component types, the **lead-free solders tested are not as reliable as eutectic SnPb solder** with respect to vibration. **Rework** also had a **negative** effect on both SnPb and lead-free solders with respect to vibration.
- For severe vibration environments, the use of lead-free solders may require the use of stiffeners, bumpers, or vibration isolators to reduce PWA flexure and reduce solder joint strains to acceptable levels.





# Vibration Testing

Percentage of Components Failed (Includes Mixed Solders)  
NASA-DoD Test Vehicles Only

Component	% of Components Failed During Vibration Testing				
	"Manufactured" Test Vehicles			"Rework" Test Vehicles	
	SnPb Paste	SAC305 Paste	SN100C Paste	SnPb Paste	Pb-Free Paste
BGA-225	84	98	100	100	100
CLCC-20	32	43	90	35	68
CSP-100	62	73	70	62	80
PDIP-20	98	92	100	88	96
QFN-20	0	21	20	8	10
TQFP-144	60	63	64	70	70
TSOP-50	62	73	86	77	80



# Vibration Testing

## Ranking of Solder Alloy/Component Finish Combinations NASA-DoD Test Vehicles Only

Relative Ranking (Solder Alloy / Component Finish)												
BGA-225	Sn37Pb/ Sn37Pb	SAC305/ SAC405	Sn37Pb/ SAC405	SAC305/ Sn37Pb	Rwk Flux Only/ Sn37Pb	Rwk Flux Only/ SAC405	Rwk Sn37Pb/SAC405 (SnPb Profile)	Rwk Sn37Pb/SAC405 (Pb-Free Profile)	SN100C/ SAC405			
	1	3	3	3	3	3	3	3	3			
CLCC-20	Sn37Pb/ Sn37Pb	SAC305/ SAC305	Sn37Pb/ SAC305	SAC305/ Sn37Pb	SN100C/ SAC305							
	1	1	2	3	3							
CSP-100	Sn37Pb/ Sn37Pb	SAC305/ SAC105	Sn37Pb/ SAC105	SAC305/ Sn37Pb	Rwk Flux Only/ Sn37Pb	Rwk Flux Only/ SAC105	Rwk Sn37Pb/SAC105 (SnPb Profile)	Rwk Sn37Pb/SAC105 (Pb-Free Profile)	SN100C/ SAC105			
	1	1	1	2	1	2	1	3	1			
PDIP-20	Sn37Pb/ SnPb	SN100C/ Sn	Sn37Pb/ NiPdAu	Rwk Sn37Pb/ Sn	Rwk Sn100C/ Sn	SN100C/ NiPdAu						
	1	3	2	3	3	3						
QFN-20	Sn37Pb/ Sn37Pb	SAC305/ Sn	Sn37Pb/ Sn	SAC305/ Sn37Pb	SN100C/ Sn							
	1	2	1	1	2							
TQFP-144	Sn37Pb/ Sn	SAC305/ Sn	Sn37Pb/ NiPdAu	SAC305/ NiPdAu	Sn37Pb/ Sn37Pb Dip	SAC305/ SAC305 Dip	SN100C/ Sn					
	1	1	1	2	1	2	1					
TSOP-50	Sn37Pb/ SnPb	Sn37Pb/ Sn	Sn37Pb/ SnBi	SAC305/ Sn	SAC305/ SnBi	SAC305/ SnPb	Rwk Sn37Pb/ SnPb	Rwk Sn37Pb/Sn (SnPb Profile)	Rwk Sn37Pb/Sn (Pb-free Profile)	Rwk SAC305/ SnBi	SN100C/ Sn	SN100C/ SnBi
	1	2*	2*	2*	2*	2	2	2*	2*	2	2	2

\*Performance relative to Sn37Pb control may depend on orientation of the TSOP






1 = as good as or better than Sn37Pb control

2 = worse than Sn37Pb control

3 = much worse than Sn37Pb control



# Testing

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- Combined Environments Testing **Raytheon**
- Drop Testing  **CELESTICA.**
- Thermal Cycle Testing (-55/+125°C) **Rockwell Collins**
- Vibration Testing  **BOEING®**  **CELESTICA.**
- Mechanical Shock Testing  **BOEING®**



# Mechanical Shock Testing

- Level 1: 100 shock pulses using a 20 G SRS
  - ❑ Functional Test for Flight Equipment; MIL-STD-810G, Method 516.6
- Level 2: 100 shock pulses using a 40 G SRS
  - ❑ Functional Test for Ground Equipment; MIL-STD-810G, Method 516.6
- Level 3: 100 shock pulses using a 75 G SRS
  - ❑ Crash Hazard Test for Ground Equipment; MILSTD-810G, Method 516.6
- Level 4: 100 shock pulses using a 100 G SRS
- Level 5: 100 shock pulses using a 200 G SRS
- Level 6: 400 shock pulses using a 300 G SRS



# Mechanical Shock Testing

- In general, the **pure lead-free systems** (SAC305/SAC405 balls, SAC305/SAC105 balls, SAC305/Sn, and SN100C/Sn) **performed as well or better than the SnPb controls** (SnPb/SnPb or SnPb/Sn).
- Many of the **BGA failures** (SnPb/SbPb balls, SAC305/SAC405 balls, and mixed technologies) were due to **pad cratering**. This suggests that **lead-free laminates** may be the **weakest link** for large area array components.
- It should be noted that all of the surface mount components **survived** 100 shock pulses at each of the first three test levels {per *MIL-STD-810G, Method 516.6*}. This means that they effectively **passed**:
  - ❑ Functional Test for Flight Equipment **33 times**
  - ❑ Functional Test for Ground Equipment **33 times**
  - ❑ Crash Hazard Test for Ground Equipment **33 times**

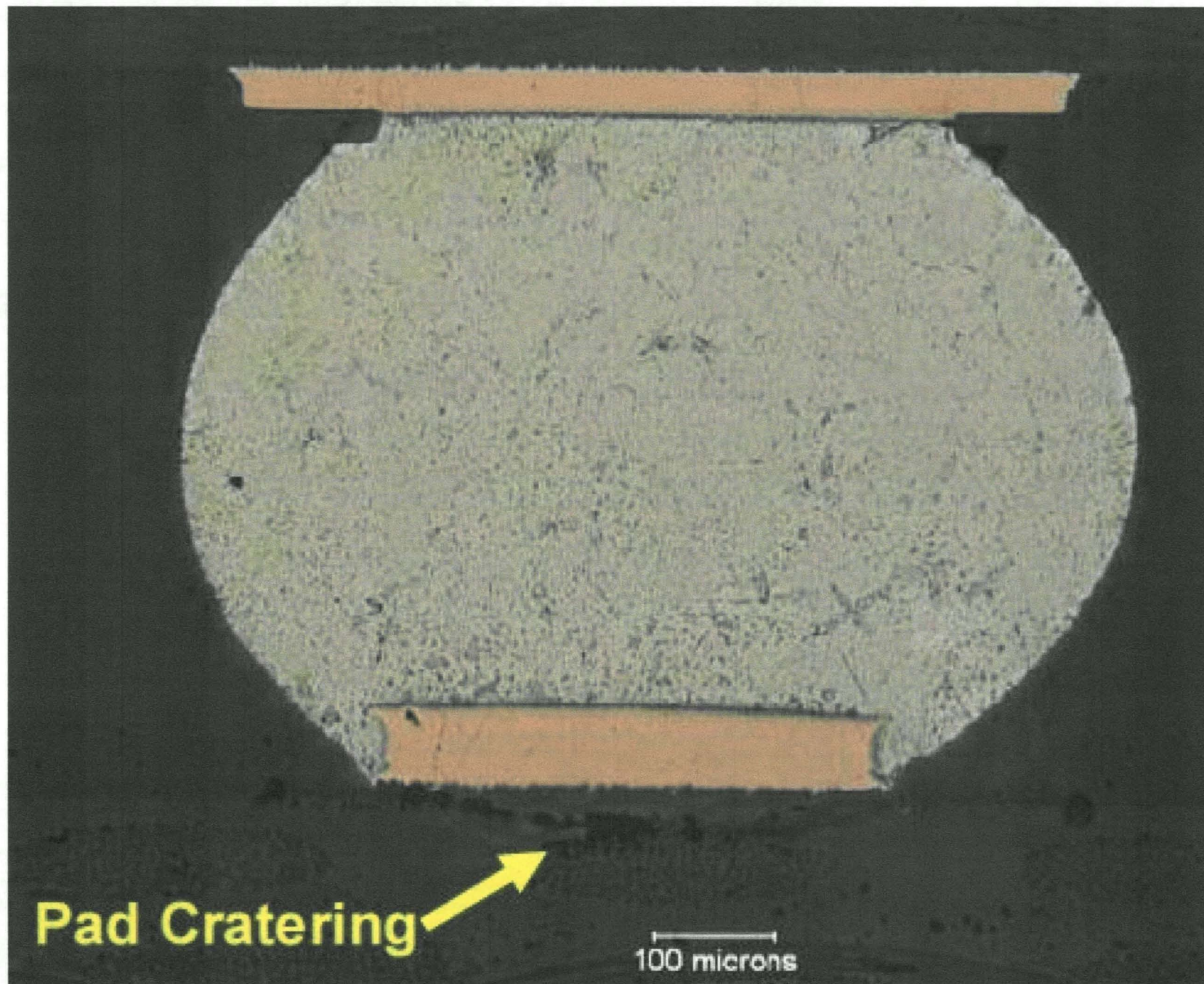


# Mechanical Shock Testing

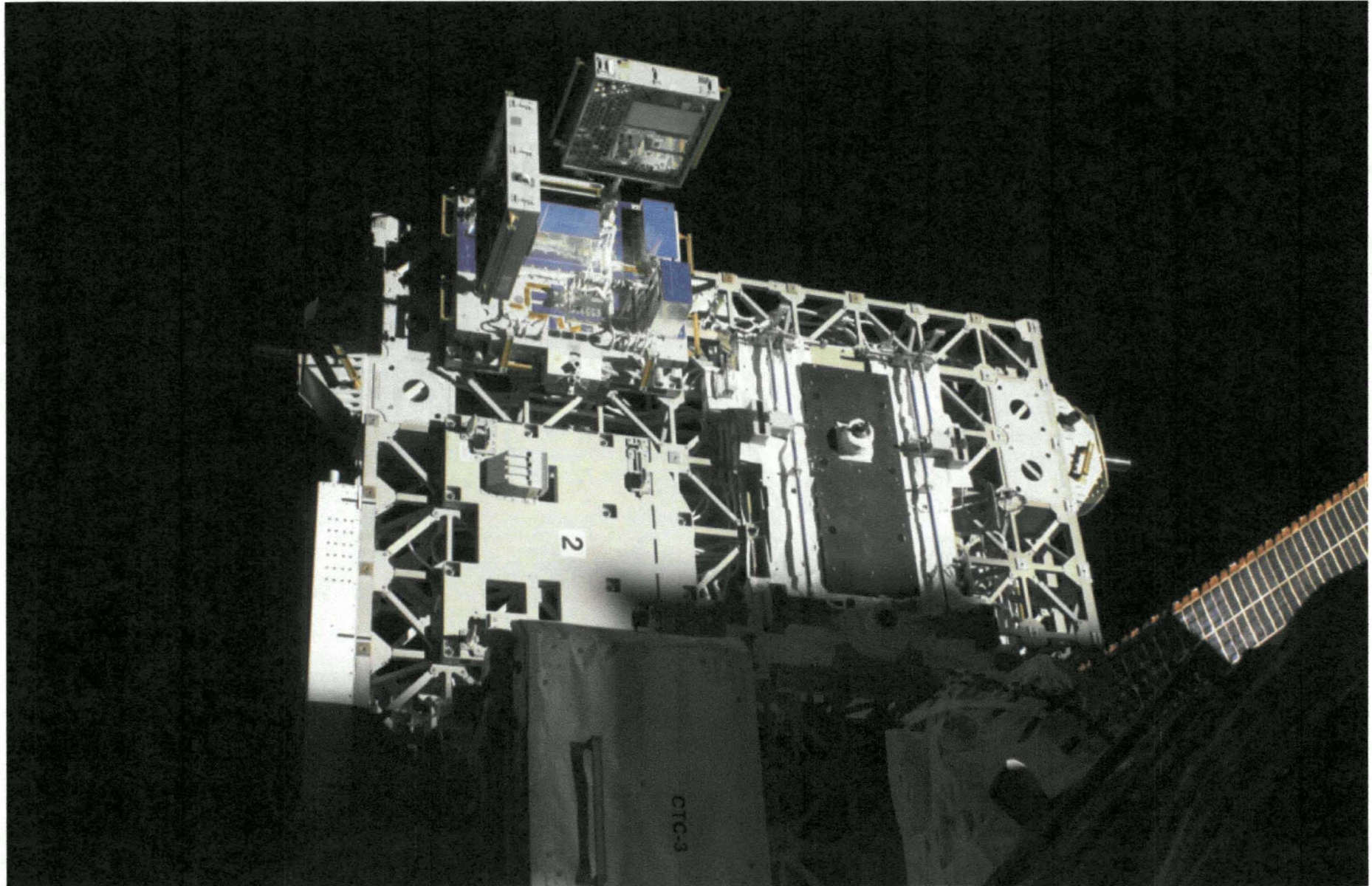
## Relative Ranking (Solder/Component Finish)

Component	Sn37Pb/Sn37Pb	SAC305/SAC405	Sn37Pb/SAC405	SAC305/Sn37Pb	Rwk Flux Only /Sn37Pb	Rwk Flux Only /SAC405	Rwk Sn37Pb/SAC405 (SnPb Profile)	Rwk Sn37Pb/SAC405 (Pb-Free Profile)		
BGA-225	1	1	2	1	1	1	2	1		
Component	Sn37Pb/Sn37Pb	SAC305/SAC305	Sn37Pb/SAC305	SAC305/Sn37Pb						
CLCC-20	1	2	2	2						
Component	Sn37Pb/Sn37Pb	SAC305/SAC105	Sn37Pb/SAC105	SAC305/Sn37Pb	Rwk Flux Only /Sn37Pb	Rwk Flux Only /SAC105	Rwk Sn37Pb/SAC105 (SnPb Profile)	Rwk Sn37Pb/SAC105 (Pb-Free Profile)		
CSP-100	1	1	2	1	2	1	2	2		
Component	Sn37Pb/SnPb	SN100C/Sn	Sn37Pb/NiPdAu	Rwk Sn37Pb/Sn	Rwk SN100C/Sn					
PDIP-20	1	1	1	2	2					
Component	Sn37Pb/Sn37Pb	SAC305/Sn	Sn37Pb/Sn	SAC305/Sn37Pb						
QFN-20	Not enough failures to rank	Not enough failures to rank	Not enough failures to rank	Not enough failures to rank						
Component	Sn37Pb/Sn	SAC305/Sn	Sn37Pb/NiPdAu	SAC305/NiPdAu	Sn37Pb /Sn37Pb Dip	SAC305 /SAC305 Dip				
TQFP-144	1	1	1	1	1	2				
Component	Sn37Pb/SnPb	Sn37Pb/Sn	Sn37Pb/SnBi	SAC305/Sn	SAC305/SnBi	SAC305/SnPb	Rwk Sn37Pb/SnPb	Rwk Sn37Pb/Sn (SnPb Profile)	Rwk Sn37Pb/Sn (Pb-Free Profile)	Rwk SAC305/SnBi
TSOP-50	Not enough failures to rank	Not enough failures to rank	Not enough failures to rank	Not enough failures to rank	Not enough failures to rank	Not enough failures to rank	2	2	2	2

# Mechanical Shock Testing



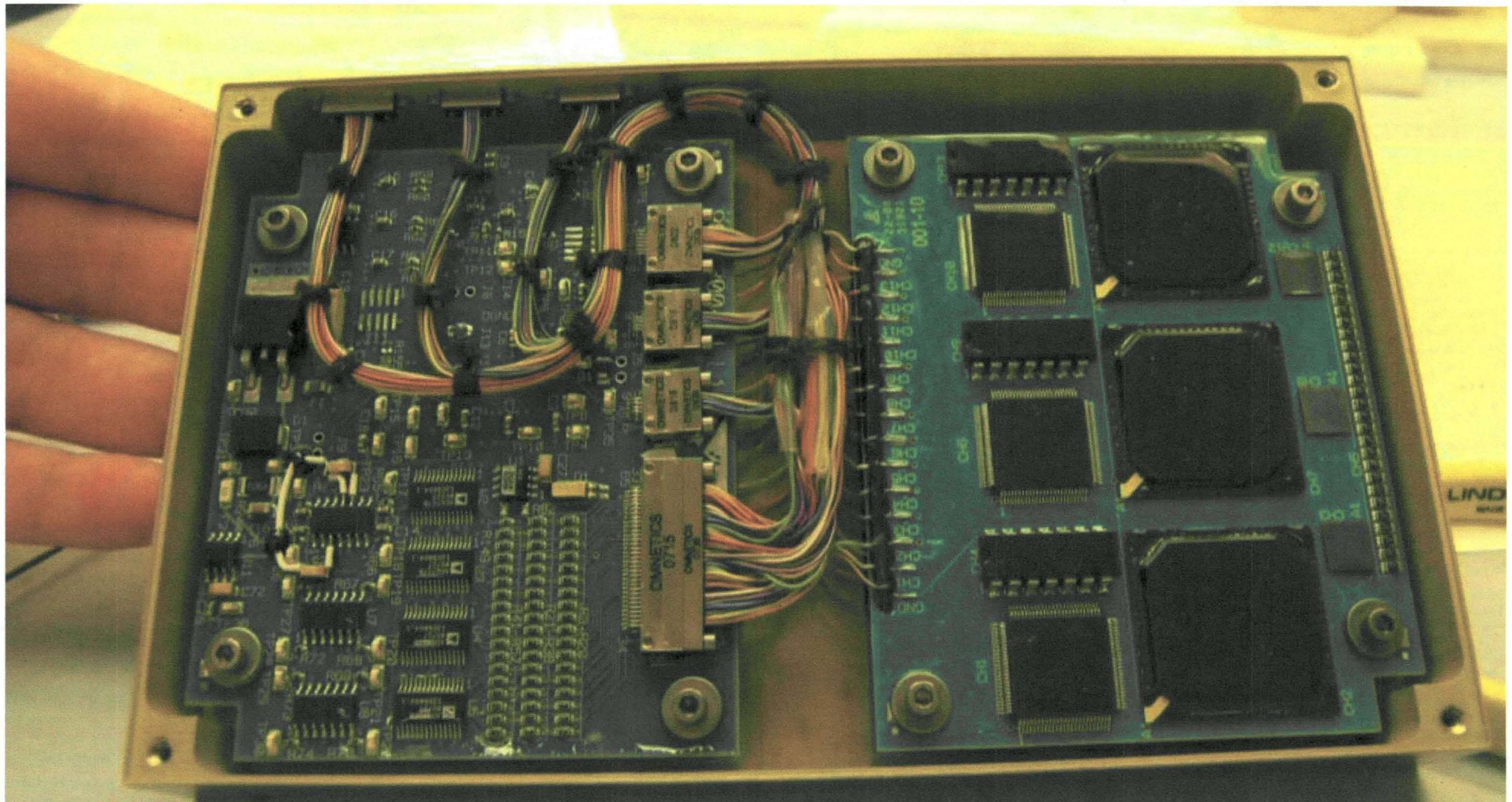
# Lead-free Technology Experiment in Space Environment (LTESE)



# Lead-free Technology Experiment in Space Environment (LTESE)



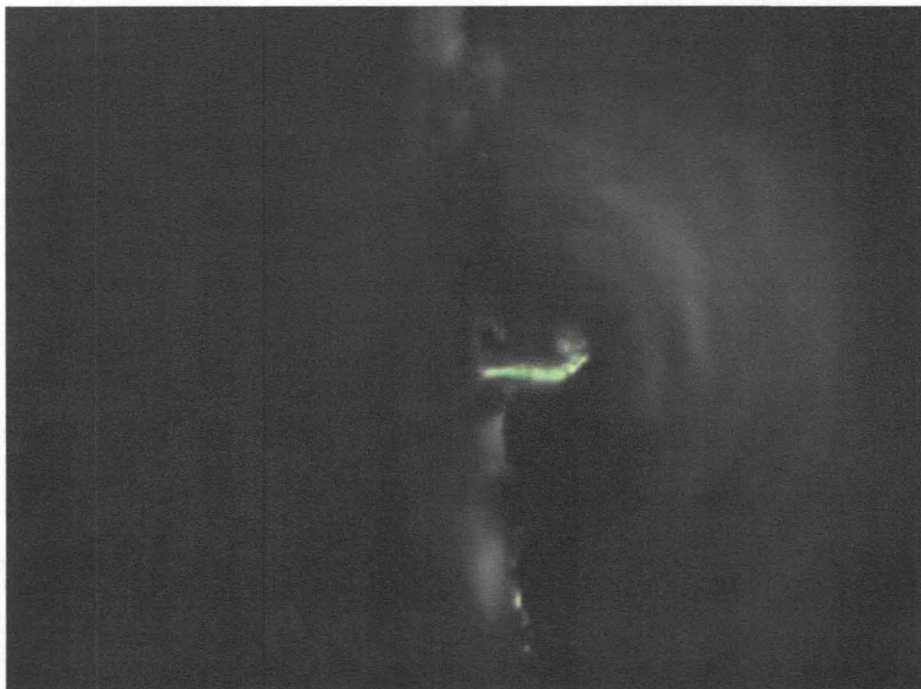
- LTESE operated for about 17 months on the International Space Station



# Lead-free Technology Experiment in Space Environment (LTESE)



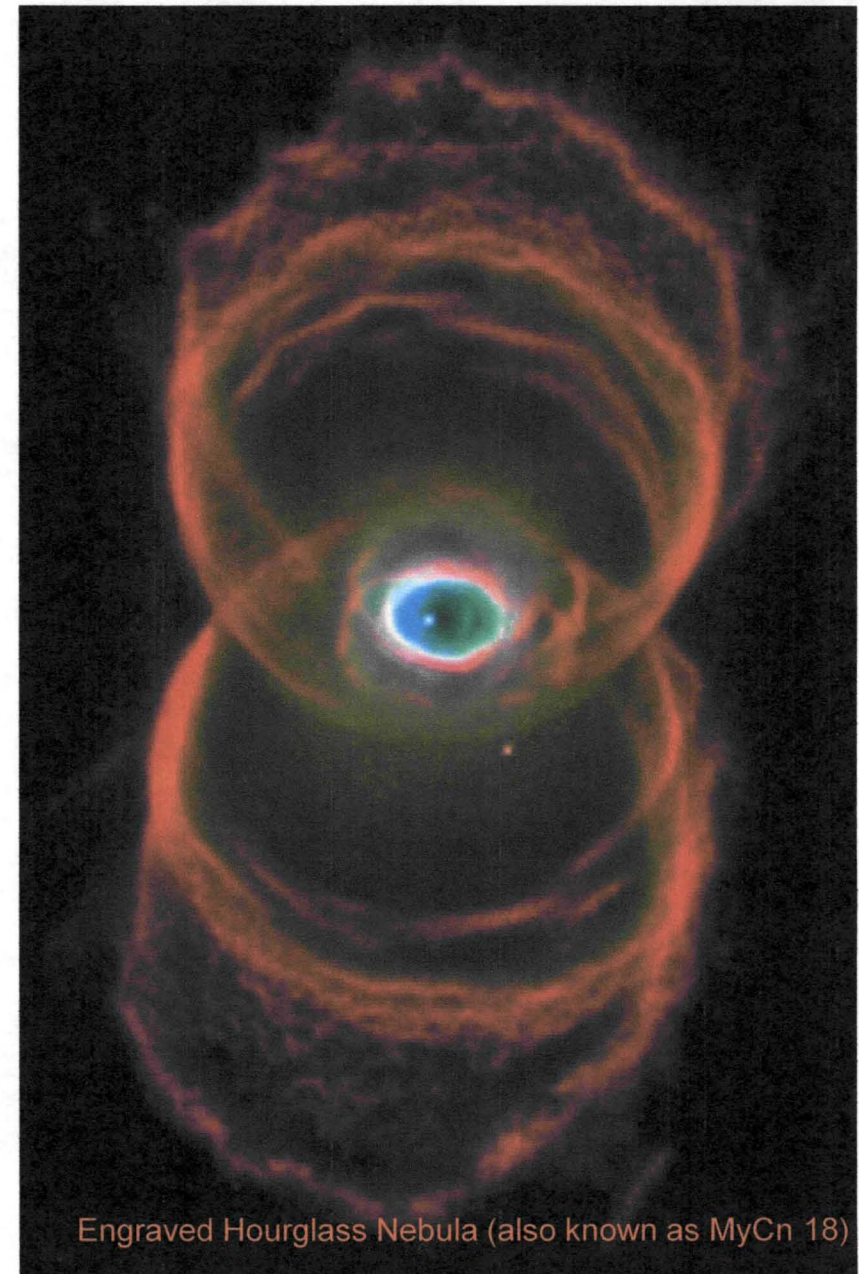
- For the LF boards, there may be signs of tin whisker growth on the PDIPs {@ 1000X}
- For the mixed solder boards, some tin whiskers have been observed on the PDIPs {@ 1000X}
  - ❑ The cards are conformal coated
  - ❑ The whiskers do not exit the coating
  - ❑ These are on the knees of PDIPs on the flight mixed solder board {SnPb board with Pb-free parts using SnPb solder}.
  - ❑ The whisker on the CH4-Lead 6 is 18  $\mu\text{m}$  long.



# Looking Forward

## What's Next?

- How do we build off of the successes of our project
- What critical gaps remain
  - ❑ System-level demonstration/validation of promising Pb-free solders on functional Class 3 aerospace and defense electronic systems. This will also help validate entire Pb-free assemblies in an operational environment.
  - ❑ Reliability data from electronic assemblies designed for operation in harsh aerospace environments {Lead-free Technology Experiment in a Space Environment (LTESE)}
  - ❑ Determine if Pb-free technology effects the functionality of electronic assemblies
- **Funding ?**



Engraved Hourglass Nebula (also known as MyCn 18)



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